DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 110

INFLUENCE OF QUALITY OF GAS AND OTHER FACTORS ON THE EFFICIENCY OF GAS-MANTLE LAMPS

BY

R. S. McBRIDE, Engineer Chemist
W. A. DUNKLEY, Associate Gas Engineer
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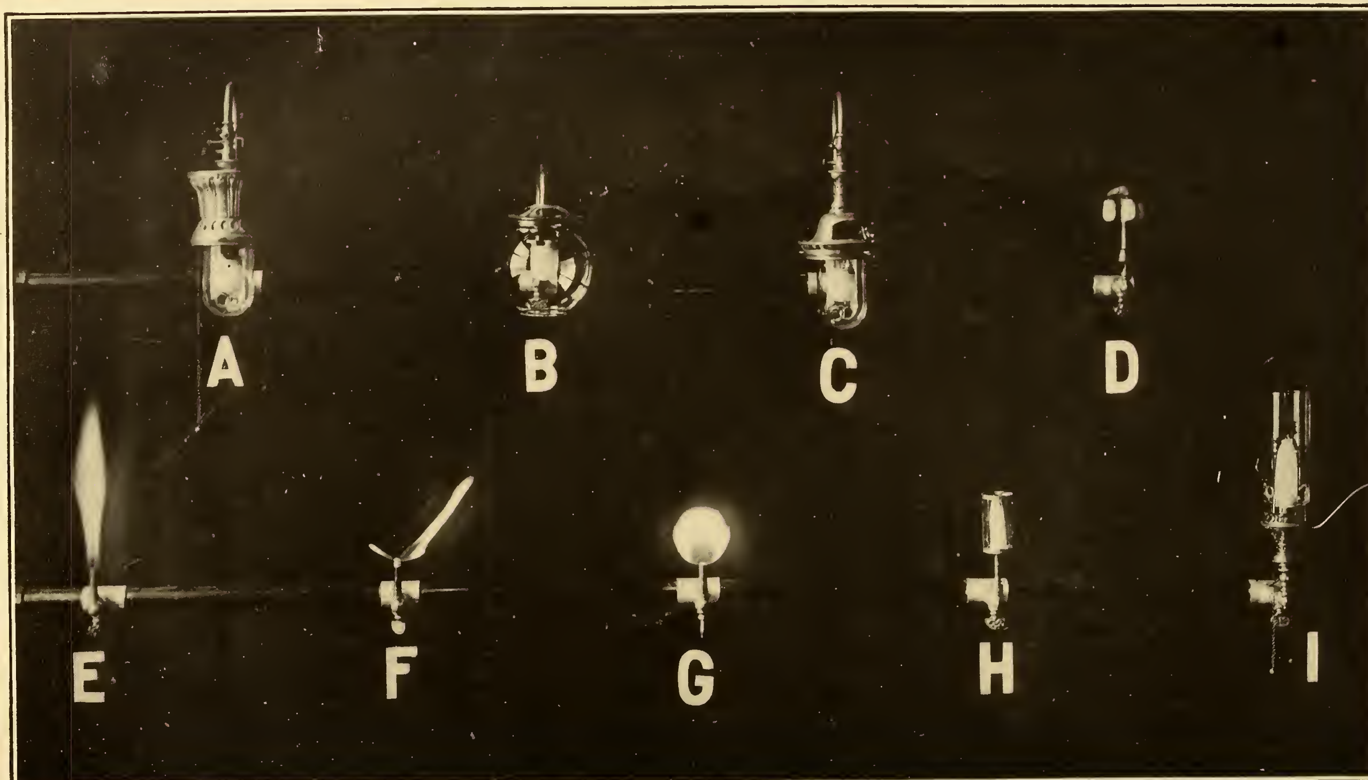

FIG. 1.—*Types of small gas-lighting units*

A, high-grade inverted mantle lamp with stack, a recent development; *B*, cheaper type of inverted-mantle lamp, has no thermostat and only crude gas regulation; *C*, usual type of high-grade inverted mantle lamp with thermostat and good gas regulation; *D*, C. E-Z, mantle lamp; *E*, open-flame burner, with lava tip missing; long, smoky flame is easily blown about by drafts and may easily set fire to surroundings; a burner in this condition is not only dangerous but extremely inefficient; *F*, open-flame burner with broken or dirty lava tip causing deflection of flame, likely to set fire to surroundings; the tip is of a type likely to be lost; *G*, well-formed open flame; tip is so fastened that it can not be easily broken or lost; *H*, junior upright mantle lamp, with mica chimney; *I*, high-grade upright mantle lamp of usual type with gas adjustment device

INFLUENCE OF QUALITY OF GAS AND OTHER FACTORS ON THE EFFICIENCY OF GAS-MANTLE LAMPS

By R. S. McBride, W. A. Dunkley E. C. Crittenden, and A. H. Taylor

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I. INTRODUCTION

1. PURPOSE AND SCOPE OF INVESTIGATION

During the past few years there has been a growing tendency throughout the country toward the substitution of heating-value standards of gas supply for the candlepower standards previously in force. In many cases this change in standards has been accompanied by a decrease in the number of heat units per cubic foot

supplied in the gas, and the question has arisen in many cases whether the usefulness of a gas for various purposes is directly proportional to the total heating value of the gas. Claims have been made by some gas engineers that within the limits of heating value of manufactured gas as usually supplied, the gases having the lower heating values can be used with higher efficiency, at least in some appliances, and also with less trouble because of imperfect adjustment of the appliances.

As a part of the general investigation to determine the relative usefulness of gases of different heating values, the Bureau of Standards has experimented with mantle lighting, cooking, water heating, and other appliances, and has made observations of some appliances in actual use on customers' premises. This paper deals with one phase of this question, namely, the usefulness of gases of various qualities when burned under laboratory conditions in certain typical commercial mantle lamps. It also incidentally shows the influence of other factors on the efficiency, candlepower, and satisfaction in use of these lamps. The results of field observations of lamps operating under commercial conditions are given in another paper[1]; and the cooking, water-heating, oven, and other appliance investigations are also to be separately reported.

2. VARIABLES INVOLVED

The efficient operation of a gas-mantle lamp depends upon the proper proportioning of the gas and air entering the lamp in order that the zone of the highest temperature may occur in the comparatively limited space near the mantle. The ordinary low-pressure mantle lamp entrains its own primary air for combustion by the injector action of the entering jet of gas. The amount of air entrained necessarily depends upon the velocity and mass of the issuing gas and these, in turn, are dependent upon the quality of the gas, its pressure, and the size and design of the gas orifice. Mantle lamps are so constructed that the size of the gas or air ports, or both, can be adjusted, and when a lamp has been adjusted to a given set of conditions, any change in these conditions, if not accompanied by a readjustment of the gas and air supply entering the lamp, may have a marked effect upon the operation. A study of the effects of these changes is therefore of first importance; and the control of the variables or the proper allowance for their effects in interpreting the results of any test is

[1] Bureau of Standards Technologic Paper 99, by R. S. McBride and C. E. Reinicker.

essential. A considerable portion of this paper therefore deals with these variables and the effects produced by them.

The efficiency of the use of gas in mantle lighting is largely determined by the following variables, several of which have been investigated more or less completely:

1. Peculiarities of the lamp, as determined by design of the type and by the variations of individual units of a type.
2. Condition of the lamp, especially the freedom from those partial obstructions in gas and air passages which are often very detrimental to efficiency.
3. Quality of the mantle.
4. Character of gas, including composition, density, heating value, etc.
5. Lamp adjustment, both gas rate and air-shutter position.
6. Atmospheric conditions, especially humidity, barometric pressure, and air currents about the lamp.
7. Pressure of gas supply.

It is obvious that some of the above-named variables are under the control of the observer while others can not be readily controlled; but the effects of all have to be considered. The difficulty of control of some of the variables, even under laboratory conditions, and the complexity of their effects in many cases, make the investigation of mantle lamps necessarily less precise than the investigation of types of apparatus in which all the conditions are under control. There is still much to be learned about the conditions affecting lamps, and only after a very extended study and a standardization of lamps and accessories could the operation of lamps under a given set of conditions be precisely predicted and all the present irregularities of operation be explained. While at times these irregularities have been very annoying, it is believed that, in general, their effect has been sufficiently eliminated in this work to make the comparisons reliable within the limits of accuracy attainable.

3. CONDITIONS OF COMPARISON

The efficiency of a lamp—that is, the output of light per unit of heat liberated by the gas in a given time—is different under different conditions. Hence, in comparing the efficiencies of operation of a lamp supplied with different gases the conditions for comparison must be specified. The efficiency of a mantle lamp is usually expressed as the total output of the light, measured in lumens, per unit of heat supplied per hour; that is, lumens per

Btu per hour. This is equivalent to expressing the efficiency as quantity of light produced per heat unit supplied, or lumen-hours per Btu.[2]

All other conditions remaining the same, the gas and air supply to a lamp may be adjusted to give (*a*) maximum candlepower, (*b*) maximum efficiency, or (*c*) some arbitrarily chosen result depending upon local conditions. By efficiency at maximum candlepower is meant the output of light per unit of heat liberated per hour when the lamp is producing the maximum intensity of light possible under the chosen set of operating conditions, only the gas and air being adjusted to produce that result. By efficiency at maximum efficiency is meant the light output per unit of heat liberated per hour when the gas and air supply are so adjusted that the efficiency is the maximum obtainable under the other prescribed conditions. The condition mentioned in (*c*) presupposes that the air and gas adjustment have been prescribed for some special reason, as, for example, in cases where the adjustment to maximum candlepower would tend to carbon the mantles after a time and consequently the air and gas have been changed from such an adjustment to avoid this. In such instances the manner of adjustment is specified so as to make the condition more or less reproducible.

The adjustment to give the maximum candlepower of the lamp is the condition probably most nearly approached in practice, since in making the adjustment an effort is usually made to secure the greatest brilliancy possible. The eye is able to detect fairly closely the point at which maximum brightness is obtained, but since the unaided eye is not sensitive to very small changes in brightness and since the increasing brilliancy of some portions of a gas mantle is often accompanied by relative darkening of other parts, the true maximum can be obtained with certainty only with the aid of a photometer. By varying the gas and air adjustments and at the same time noting the intensity of the light with a photometer, a point can be reached where any change of adjustment in either direction results in a decrease of light intensity. This condition may be sharply defined in some cases, but in others the change of intensity is so gradual that the adjustments may be varied over a considerable range without perceptibly affecting the intensity of the light, though the efficiency may be changing quite rapidly. It should be noted in this connection

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[2] A lumen is the unit of light flux, or output, and is of such magnitude than a light of one mean spherical candle has an output of 4π (12.57) lumens.

that the control of the many variables affecting mantle-lamp operation is so difficult and a lamp is so sensitive to external influences, such as drafts, that the establishing of the true maximum to a high degree of certainty is well-nigh impossible.

The point of maximum efficiency of a lamp is accompanied by no distinctive phenomenon apparent to the observer even when aided by the photometer. Therefore, the efficiency at each observation must be determined by computation from measurements, and a sufficient number of observations at different adjustments must be made so that the maximum can be selected by graphical methods. The significance of these changes will be made more evident by the consideration of Fig. 5, which shows for four units the influence of gas adjustment upon consumption, candlepower, and efficiency. (See p. 25.)

Although not commonly realized in practice, the adjustment to give maximum efficiency is of importance in comparison of various gases and various conditions of supply, since clearly it is desirable that a lamp be operated as nearly as possible at such adjustment. Comparison has been made therefore both for adjustment for maximum candlepower and for maximum efficiency. The relative efficiencies with the different conditions of supply and operation were thus determined by comparing lumens per Btu per hour for the several combinations contrasted.

By fitters' adjustment is meant any arbitrary method of adjustment which is prescribed to accomplish some special result, such as the avoidance of carboning mantles or the attainment of good operation under predicted service conditions which may be somewhat different from the conditions existing at the time of adjustment. For example, a lamp may be adjusted during the daytime for the pressure or other conditions which are expected to obtain at night. This will be further discussed in a later portion of this paper.

4. GASES USED FOR COMPARISON

Since the chief object of the work presented in this paper was to study the operation of lamps with various gases, one of the first problems was to supply the various gases in adequate amounts for testing. It was decided to confine the study to gases typical of those supplied in practice to various communities; and since the Bureau had received special inquiry concerning the relative usefulness of carbureted water gases of about 665 Btu and of 565

Btu, and of coal gas of 565 Btu, these were selected as the typical gases to be studied. For the sake of comparison and further study of certain variables, some specially enriched gases of higher heating value were also used in a few cases. Since typical commercial gases vary from time to time within certain limits, both as to composition and heating value, it was not considered necessary to maintain exactly the same quality of gases throughout the various series of tests; nor was it practicable to do so. An effort was made, however, to prevent as far as possible variations between sets of observations which were intended to be comparable.

II. PREVIOUS WORK

A number of investigators have studied the relation between the heating value of the gas burned and the mantle-lighting efficiency obtained. The problem has been attacked from different standpoints and widely varying conclusions have been drawn. These differences are usually explainable when the details of the investigations are known. In some cases it appears that variables other than the heating value of the gas have exerted such large influences that the effects of the variable in question have been obscured. In other cases the results obtained, while applicable to the conditions of the tests, would not be generally applicable to commercially existing conditions. The following is a summary of the more important of these investigations which have come to our attention:

In 1900 H. Bunte [3] reported to the International Gas Congress at Paris that from his studies he had found that gases of widely different heating values gave practically the same amount of light per cubic foot when used in mantle burners. However, no adjustment was made for gas and air and the burner was designed for gas of comparatively low heating value.

In 1902 A. H. White, H. Russell, and A. F. Traver [4] reported that other conditions being the same, the amount of light given per cubic foot by a gas when used in an incandescent gas burner (adjusted to give maximum candlepower at 2 inches gas pressure in each case) was proportional to the net heating value and increased at the rate of one candle for each increase of 4 calories (15.87 Btu) in the heating value per cubic foot. In their experiments they

[3] Bunte, Mayer, and Teichel, J. für Gasbeleuchtung, **51**, p. 265; 1908.

[4] Am. Gas Light Jour., **76**, p. 413; 1902.

used a "C" upright Welsbach burner and a Welsbach mantle. They stated that the point of maximum efficiency coincided with the point of maximum candlepower in all cases. The gases tested by them ranged in quality from 246 to 1050 Btu per cubic foot and included carbon monoxide, hydrogen, blue water gas, carbureted water gas, coal gas, natural gas, Pintsch gas, and various mixtures of gases. They found that whereas the natural gas and Pintsch gas, especially the former, varied quite widely from the general rule, those gases representing the usual qualities supplied by gas companies followed the rule very closely.

In 1903 St. Claire-Deville [5] of the Paris gas works reported that his work showed that the lighting effect produced by gas used in incandescent mantle burners was, apart from differences in mantles, proportional to the net heating value of the gas, providing the gas was burned in each case with the amount of air suited to it. He found it necessary, however, to supply air under pressure for the perfect combustion of some of the very rich gases.

In 1908 Max Mayer and H. Schmidt [6] discussed the work of St. Claire-Deville and presented data to show that while Deville's conclusions established a useful rule for judging the value of a commercial illuminating gas for mantle lighting, they did not apply in all cases to the behavior of special mixtures of illuminating gas with hydrogen or with carbon monoxide, even though burned with the same rate of heat liberation, equal flame volume, equal flame temperature, and the same form of flames, on account of the degree of dissociation of carbon dioxide when gas mixtures producing large proportions of carbon dioxide in their combustion products are burned.

In 1909 Arthur Forshaw [7] reported some work done by him at the University of Leeds on the comparative efficiencies of hydrogen and carbon monoxide when burned in mantle burners. He found that burned in an ordinary atmospheric burner, carbon monoxide gave a much higher "duty" than hydrogen and concluded that the illuminating efficiency of a mantle burner is not necessarily proportional to the heating value of the gas.

Max Mayer [8] reported in 1910 some investigations in which he took samples of the gas and air mixtures from the mixing tube of an upright mantle burner and studied the gas-air ratio in each case in connection with the luminous efficiency of the burner.

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[5] Jour. Gas Lighting (London), 83, p. 499; 1903.
[6] Jour. für Gasbeleuchtung, 51, p. 1137; 1908.
[7] Jour. Gas Lighting (London), 106, p. 865, 1909.
[8] Jour. für Gasbeleuchtung, 53, p. 933, 1910.

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He concluded that the composition of the gas and its velocity of efflux play almost a greater part than does the quantity of air drawn in, and that as the heating value falls and the proportion of heavy hydrocarbons decreases the efficiency increases in mantle lamps which entrain their own air at low pressures. He also concludes that the higher the percentage of hydrogen becomes the higher is the efficiency. Finally he concludes that while St. Claire-Deville's conclusions are within a few per cent applicable to the usual commercial illuminating gases, they would not be applicable to gases of higher or lower heating values in ordinary low-pressure burners. He criticised Forshaw's conclusions upon the ground that owing to the greatly differing properties of hydrogen and carbon monoxide they could not be fairly compared with the same burner.

In 1915 R. F. Pierce[9] reported some observations of the behavior of mantle lamps with various water gases. The tests were performed with an upright lamp and "were planned with a view to demonstrating that calorific value, specific gravity, and gas candlepower do not definitely specify a gas for commercial purposes," but that the composition of the gas and the flame temperature which is will produce are the determining factors. Pierce presented tables and curves to substantiate his position and from these concluded that his a priori statement was proved. He drew the far-reaching conclusion that neither gas candlepower, specific gravity, or calorific value, are of the slightest value in predetermining the performance of a lamp or in fixing standards of service for gas lighting. However, one of us[10] reviewed Pierce's work and showed that he was not justified in drawing the conclusions which he did from his own data. It was demonstrated that if Pierce's results were properly grouped—for example, for each 20 Btu interval of heating value of the gas—these same data would prove for gases within the commercial ranges of heating value now existing, just the opposite of Pierce's conclusions. In other words, they show that for commercial ranges of heating value the usefulness of the gas for mantle lighting is directly proportional to the gross heating value of the gas.

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[9] Am. Gas Light Jour., 103, p. 1, 1915.

[10] R. S. McBride, Am. Gas Light Jour., 103, p. 353, 1915.

III. EXPERIMENTAL APPARATUS AND METHODS

1. LAMPS AND ACCESSORIES

The lamps used in the work discussed in this paper comprise the following higher-priced units of Welsbach make: No. 6 Reflex, No. 71 Upright, Junior, and C. E-Z; tests were also made with the Welsbach No. 7 inverted lamp and some lamps of the upright and junior types purchased in 5-and-10-cent stores. Some of the lamps tested are shown in Fig. 1. All the lamps were practically new and were not changed in any way, except that one Junior lamp was provided with an accurately centered needle valve, so as to make the distribution of the gas mixture within the mantle more symmetrical.

In making photometric tests with the various lamps the only forms of glassware used were the plain cylinders for the Reflex and upright lamps. The regular mica chimney was used with the Junior, and the C. E-Z lamp was used without any glassware whatever. When candlepower was to be taken in one direction only, the lamps were set up before a black background so as to avoid errors from reflected light. The lamps were also shielded from drafts of air, but not sufficiently to interfere with proper ventilation. It was found necessary in most cases to keep all windows closed, as it was found that all the lamps were very sensitive to air currents even though shielded fairly well. In all tests of upright and inverted lamps regular mantles as supplied on Government contracts were employed; for Junior and C. E-Z lamps the mantles furnished by the makers of the lamps were used.

2. LAMP ADJUSTMENT

After setting up the lamp to be used it was lighted and allowed to burn, under ordinary conditions, for at least one-half hour before any observations were made. This was important since it was found that a lamp, even with a mantle which had been used several hours, did not reach its maximum candlepower at any adjustment until several minutes after lighting. If the mantle was a new one, a longer period was always allowed.

When the conditions of gas supply for the test had been established, the adjustment of the lamp was made by one observer while another read the photometer and kept the conditions external to the lamp constant as far as possible. In adjusting a lamp

the gas screw or other regulating device was manipulated until the desired condition was reached as judged by the photometer or by the gas rate if the latter was the determining factor in the adjustment. The air shutter was then manipulated until its position to give maximum intensity for this gas rate was reached. In general, the air shutter was wide open; and in the later sections of this paper when no mention is made of this detail the shutter may be understood to have been so placed.

3. PHOTOMETRIC APPARATUS

Several photometers with their accessories were used in this work. In all cases the comparison was made between the gas lamp and an electric standard of known value; the difference in color in all cases was compensated for by a color cell or glass placed in the path of the light from the electric lamp to the photometer. In some of the runs the lamp was placed in an 88-inch integrating sphere and the mean spherical candlepower measured directly. In most cases, however, the intensity of the light in only one direction was determined; and the mean spherical candlepower when needed was computed by applying suitable reduction factors. The candlepower of upright-mantle lamps was observed in the horizontal direction and of inverted and C. E-Z units at an angle of 20° below horizontal. Unless otherwise qualified the term "candlepower" as used in this paper refers to the intensity in these directions.

The other photometers used in such comparisons included a standard model Sharp-Millar portable photometer and a Schmidt and Haensch (Bechstein) universal photometer. Each of the photometers was equipped with suitable rheostats and volt or millivolt meters to keep the intensity of the comparison lamp constant. The comparison lamps were calibrated at suitable intervals against standard lamps.

4. ACCESSORY APPARATUS

The gas rate was measured in each case by a calibrated laboratory wet test meter timed by a stop watch, correction being made to standard conditions of temperature and pressure.

Gas pressure was measured by a water manometer and the pressure during a given run was kept constant either by a wet pressure regulator or by a dry photometer governor.

A mercury barometer, Assman psychrometer, and U. G. I. dew-point apparatus were used to determine the atmospheric pressure, atmospheric humidity, and the oil and water dew points of the gas, respectively.

5. PREPARATION AND TESTING OF GAS SAMPLES

The city gas available for use in testing at this Bureau was a mixed water and coal gas of about 650 Btu per cubic foot. In order to make gases of other qualities, resembling typical water and coal gas, the city gas was used as a basis and varying proportions of the constituents were added to obtain the desired composition. For the manufacture of a gas resembling straight water gas it was necessary to add carbon monoxide and hydrogen in proper amounts to the city gas; while in producing a gas resembling coal gas it was necessary to add methane, hydrogen, and carbon dioxide to the city gas. The carbon monoxide was obtained by the decomposition of sodium formate with sulphuric acid, the hydrogen was produced electrolytically, and the carbon dioxide was commercial material available in cylinders under pressure. The methane was obtained in the form of natural gas from a gas field in western Pennsylvania, very rich in methane; it was shipped to us in cylinders at about 275 pounds' pressure.

It was not found practical to bring the synthetic mixture to exactly the same composition in each case; but having found the average composition of the city supply from a number of analyses, it was possible to approximate very closely the desired composition and also to obtain the Btu desired. The usual procedure was to introduce the estimated amount of each special gas into a gas holder of 30 cu. ft. capacity and then to fill the tank to the limit of its capacity with the city gas.

After making up the sample it was allowed to stand several hours to become thoroughly mixed, or in cases where convenient the gas was forced back and forth several times from one tank to another to hasten the mixing of the sample. The heating value and in some cases the open-flame candlepower and specific gravity were then determined and a sample of the gas was taken for analysis.

While the composition of the various gases varied from day to day, the data of Table 1 are representative analyses, being averages of many of each type of gas. (See Appendix.)

TABLE 1.—Typical Gas Analyses

	City gas (mixed)	Water gas	Coal gas	Enriched gas
CO_2	4.1	4.4	5.1	3.5
O_2	.6	1.0	1.3	.3
Illuminants	10.1	6.9	3.9	13.4
CO	19.7	26.2	7.0	19.1
CH_4	23.9	18.9	30.0	25.3
H_2	35.9	38.5	47.1	34.7
N_2	5.7	4.1	5.6	3.6
Btu (average)	650	550	570	740
Candlepower	18	7	Below 7	25
Sp. grav	.61	.60	....	.64

The heating value of each sample of gas used was carefully determined; but since it was found that the city gas gave a fairly uniform analysis over considerable periods, analyses of that gas were made less frequently than of the synthetic water and coal gases, practically all of which were analyzed. As may be noted from the analyses, the city gas is about 80 to 85 per cent water gas, the remainder being coal gas. The city gas showed variations in heating value through the period of the tests from 618 to 686 Btu, the water gas from 487 to 590, the coal gas from 540 to 592, and the benzol-enriched city gas from 697 to 781 Btu. However, the heating value of the water gas used in tests for studying the direct comparisons of operation of city and water gas in lamps was always about 560 to 565 Btu, while the average values of the other gases were about as given in the table above.

6. RECORDING AND COMPUTING RESULTS

For convenience of presentation in this paper the work done has been divided into series. A series included all the experiments made to show the effects of a certain variable condition upon the operation of the various lamps. The work of a series extended in some cases over a period of several days and was divided into runs. A run was usually the work of one day or in some cases only a few hours. During a single run a single condition was varied and all other operating conditions were kept constant, or if this was impossible any changes were observed and recorded so that their effect could be corrected. A run included several sets of observations, all of which were comparable with each other. In some cases two or more runs were made the same day under conditions which made the runs comparable. A single set of observations

included the data obtained for each single value of a variable, all other conditions remaining constant. Table 2 shows a typical data sheet for a single run.

TABLE 2.—Typical Data Sheet

Series No., 1; Run No., 1; Sheet No., 1; Date, July 19, 1916; Lamp, No. 6 Reflex; Air shutter, open; Fixture cock, open wide; Gas No., 34; Btu, 650; Photometer factor, glass in, 23.13, out 5.0; Meter temp., 70; Bar. (corr.), 29.57; pressure at meter, 5 in.; Factor, 0.970; Humidity: Dry bulb, ——; Wet bulb, ——; L. per cubic meter, ——.

Set No.	Gas pressure, inches	Adjustment pressure, inches	Gas rate			Photometer readings						Candlepower	Candles per cubic foot
			Time, seconds per revolution	Cubic feet per hour (uncorrected)	Cubic feet per hour (corrected)	1	2	3	4	5	Average		
[a] 1	1	3	146	2.5	2.4	3.19	3.10	3.10	3.26	3.19	3.17	15.8	6.6
2	1½	3	112	3.2	3.1	2.03	2.02	2.02	2.09	2.08	2.05	47.4	15.3
3	2	3	96	3.7	3.6	2.70	2.74	2.70	2.70	2.71	2.71	62.7	17.2
4	2½	3	87	4.1	4.0	2.90	2.93	2.96	2.95	2.90	2.93	67.8	16.9
5	3	3	80	4.5	4.4	3.10	3.12	3.13	3.13	3.19	3.13	72.4	16.6
6	3½	3	74	4.9	4.7	3.42	3.40	3.40	3.41	3.42	3.41	78.9	16.7
7	4	3	70	5.1	5.0	3.60	3.61	3.67	3.72	3.68	3.66	84.7	17.0
8	4½	3	66	5.4	5.3	3.40	3.40	3.41	3.39	3.40	3.40	78.6	14.9
9	5	3	60	6.0	5.8	3.42	3.40	3.35	3.39	3.27	3.37	78.0	13.4

[a] Glass out; all others, glass in.

In computing the results, the gas rate per hour for each set was computed from the time elapsed during a meter revolution, the volume being corrected for temperature and barometric pressure in the usual manner. The average candlepower for each set was usually obtained by averaging all the photometric observations for each set and multiplying this average by a factor which converted the photometer reading to spherical candles. This factor took into account the constant of the photometer and the reduction factor for converting the candlepower in the direction observed to mean spherical candles. In most cases where the same gas was used throughout a run, the efficiency was expressed simply in candles per cubic foot per hour; the candlepower observed in a given direction was used, since the reduction factor to mean spherical candlepower had been found to be practically constant with different adjustments. In some cases the efficiency was further expressed in lumens per Btu per hour, determined by multiplying the mean spherical candlepower by 12.57 (4π) to get lumens, and then dividing by the Btu per cubic foot of gas times the rate of gas consumption per hour.

7. DIFFICULTIES ENCOUNTERED

The difficulties encountered in this work were chiefly caused by external influences or by peculiarities of the individual lamps tested. Some of these difficulties are here mentioned to aid others in similar work.

As has been mentioned before, it was found that the lamps were very sensitive to drafts. While this would not necessarily be of consequence in commercial operation, it was very annoying where the effects of small variations of operating conditions were to be determined. It was found necessary to work in a room free from drafts and as an added precaution to shield the lamps by screens.

Another factor which had to be considered was the lag in the candlepower change caused by changing conditions. Not only was it necessary to delay making observations after first lighting a lamp, but it was also found that changing the pressure or gas adjustment was followed by a gradual adjustment of the lamp to the new conditions and it was necessary to wait until the operation of the lamp became steady.

Some of the most annoying difficulties were caused by imperfections of lamp construction. For example, it was found that with some of the lamps tested the stream of gas-air mixture entering the lamp was not symmetrical with respect to the mantle, and changed shape as the gas adjustment was changed. Changes in the gas adjustment resulted in such cases in an erratic variation, not only in the relative brightness of different sides of the mantle, but also in the total light output. This peculiarity was noticeable in the upright and Junior types of lamps, especially the latter. While this irregularity might have little importance in the commercial use of the lamp, it was troublesome in this work and was only remedied by substituting in the lamp a new adjustment screw accurately fitted and symmetrical.

Another condition encountered which was not serious but which delayed the work on certain occasions was the difficulty of predicting the increase in rate of gas which would result from a change in the gas adjustment. It was found that the effect of the gas-adjusting screw or other device varied greatly with different positions of the adjustment. A small fraction of a turn in some parts of the range would cause a much greater change in the operation than one or two complete turns in other parts.

IV. RESULTS OF EXPERIMENTS

In this work, as in all gas photometry, a large number of series of tests were needed in order to establish the various conclusions; but in this paper it is desired to set forth only the conclusions and a few data typical of the numerous series carried out to establish the magnitude and direction of influence of the various factors. It should be borne in mind in considering these data that the absolute values given should not be taken as of particular significance, since in many cases they depend upon the atmospheric conditions or the methods of testing arbitrarily chosen to bring out certain particular information; and furthermore, these values would not always be reproducible with all lamps of a type even if the working conditions were duplicated. However, these differences have, in general, been wholly eliminated from influence upon the qualitative conclusions by careful control within the period of test, of the factors that might affect the particular comparison desired; and it is believed that the results given show the influence of the variables in a way typical of all lamps of the types tested.

1. DETERMINATION OF REDUCTION FACTOR

In order to facilitate the testing of mantle lamps it was necessary to make a large number of the photometric measurements with apparatus by which the intensity of the light in one direction only could be measured. In order that these measurements in a single direction might show directly the variation in the total light output from the lamp, a direction was chosen in which the intensity bore a constant relation to the mean spherical intensity under changing conditions.

A distribution photometer was used to determine the value of this reduction factor; that is, the factor by which the candlepower in one direction should be multiplied in order to determine the mean spherical candlepower. These experiments confirmed the previous conclusions of others; the results are presented here largely because of the possible interest in some of the data for the inverted and C. E-Z units.

During the measurements the lamp was so screened that only the light given off in a certain direction was reflected to the photometer by two plane mirrors. The position of these mirrors in a vertical plane relative to the lamp could be adjusted, and by

37904°—18——3

successive observations a series of values was obtained representing the intensity at different angles from a point directly below the lamp to a point directly above it. By plotting the candlepower values from these observations the distribution curves of the lamp under each operating condition were obtained.

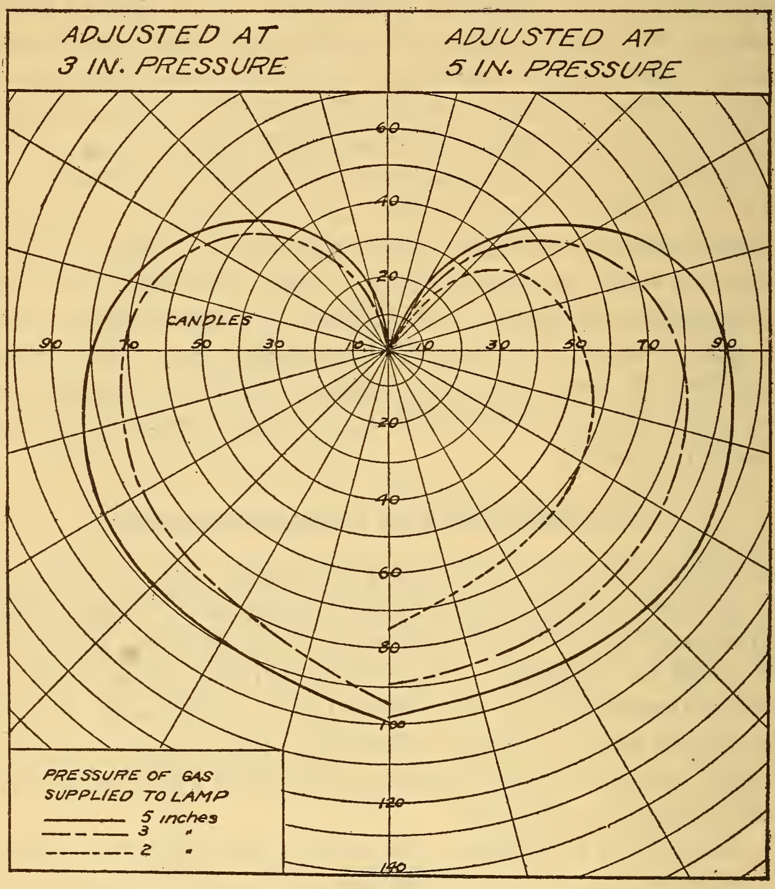

FIG. 2.—*Distribution of No. 6 Reflex lamp in a vertical plane adjusted to maximum candlepower at 3 and 5 inches gas pressure and operated at the pressures indicated*

The curves of Figs. 2 and 3 show the distribution of light determined by the distribution photometer for the No. 6 Reflex and the C. E-Z lamps. The curves on the right half of Fig. 2 show the distribution of light when the lamp viewed in a direction 20° below the horizontal was adjusted to give maximum candlepower at 5 inches pressure with mixed gas of 636 Btu, when operated at the various pressures indicated. Similarly the

curves at the left of the vertical axis give the distribution when the lamp was adjusted at 3 inches pressure.

The curves of Fig. 3 are for the C. E-Z lamp adjusted at 5 inches pressure for maximum candlepower at 20° below horizontal with mixed gas of 634 Btu per cubic foot, when operated

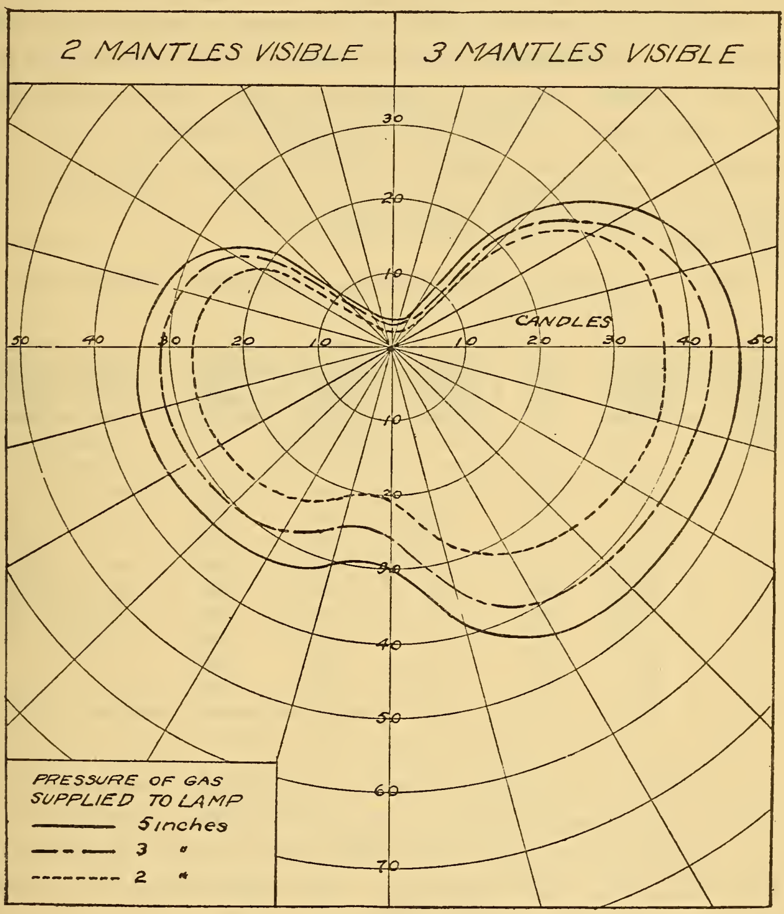

Fig. 3.—*Light distribution of C. E-Z lamp in a vertical plane adjusted to maximum candlepower at 5 inches gas pressure and operated at the pressures indicated*

at the pressures shown. The curves show the difference in candlepower when two or three mantles are visible and make clear the lack of uniformity in the light distribution. To determine these values for the C. E-Z unit the right and left mirrors of the photometer were used alternately, the one not in use being covered with a black cloth.

To determine the reduction factor from these data the mean spherical candlepower of the lamp under the given conditions was computed by multiplying the intensity at each 10° interval by the factor representing the ratio of the area of a zone measured 5° each side of that angle to the total area of a sphere. The sum of all the products thus obtained gave the mean spherical candlepower of the lamp. It is obvious that zones of surface which are bounded by small circles—that is, those near the vertical axis—have the smallest area and consequently are of least importance in the calculation. The most important directions, in which the intensities should be carefully established, are those near the horizontal. The following tabulation (Table 3) illustrates the use of such data for the Reflex lamp.

TABLE 3.—Computation of Mean Spherical Candlepower of Reflex Lamp

Zone measured (angle from point directly beneath lamp)	Spherical-candlepower constant (relative area of zone) A	Candle-power B	Weighted candle-power (A times B)	Zone measured (angle from point directly beneath lamp)	Spherical-candlepower constant (relative area of zone) A	Candle-power B	Weighted candle-power (A times B)
0°	0.002	93	0.2	100°	0.086	86	7.4
10°	.015	96	1.5	110°	.082	78	6.4
20°	.030	96	2.9	120°	.076	64	4.9
30°	.044	96	4.2	130°	.067	50	3.4
40°	.056	98	5.5	140°	.056	36	2.0
50°	.067	98	6.6	150°	.044	22	1.0
60°	.076	98	7.4	160°	.030	12	.4
70°	.082	97	8.0	170°	.015	6	.1
80°	.086	94	8.1	180°	.002	0	.0
90°	.087	91	7.9	Total, mean spherical candlepower=			77.9

This method of computation of mean spherical candlepower was applied to the data for the C. E-Z and the Reflex lamps and then the ratio of the mean spherical candlepower and the candlepower in various directions was computed. The results of two such series of computations are shown in Table 4.

These data show that for the Reflex lamp there is little choice between measurements at any angle from the horizontal to 50° below horizontal, since the reduction factor under different conditions of operation appears to be approximately constant at any of these angles. With the C. E-Z lamp the reduction factor appears to be nearly constant for angles about 20° to 30° below horizontal. These conclusions confirm the work done by others which indicated that for observations at about 20° below horizontal the reduction factor was substantially constant. This angle was

also conveniently obtained with the apparatus which was at hand, and therefore throughout later work observations of the Reflex and the C. E-Z lamps were made in this direction.

Similar work was done on the upright mantle and Junior lamps. This showed a constant value for the reduction factor from horizontal candlepower to mean spherical candlepower. This is to be expected on account of the shape of the mantles.

TABLE 4.—Reduction Factor

REFLEX NO. 6 LAMP

Angle below horizontal	Lamp adjusted at 5 inches pressure and operated at—			Lamp adjusted at 3 inches pressure and operated at—		Average value	Maximum deviation from average
	5 inches	3 inches	2 inches	5 inches	3 inches		
Horizontal	0.854	0.885	0.914	0.912	0.897	0.892	0.038
20° below horizontal	.801	.791	.812	.852	.820	.815	.037
30° below horizontal	.792	.772	.785	.835	.811	.799	.036
40° below horizontal	.792	.767	.765	.819	.801	.789	.030
50° below horizontal	.797	.770	.747	.803	.797	.783	−.036
60° below horizontal	.809	.771	.724	.789	.797	.778	−.044
C. E-Z LAMP							
Horizontal	0.827	0.794	0.802	0.794	0.774	0.798	0.029
20° below horizontal	.804	.788	.798	.772	.789	.790	−.018
30° below horizontal	.815	.808	.809	.790	.830	.810	−.020
60° below horizontal	.844	.851	.905	.816	.926	.868	−.058

The absolute value of the reduction factor is of no great importance in any of the work of the following sections since in practically all cases only the relative values on each lamp were of consequence. Nevertheless, in several instances it was found convenient to convert the observations to mean spherical candlepower. The results given above for the Reflex and C. E-Z lamps indicate that the average for the former is slightly above 0.80 and for the latter slightly below this figure. The work of others indicated that 0.80 was the correct factor, and therefore we have employed this for both the Reflex and the C. E-Z lamps. For upright-mantle lamps we have used the factor 0.75, basing our choice not only upon our own work but also upon results of several previous workers. It is desired to emphasize again that the absolute value of these factors is of no consequence since in most of our work the conclusions might about as well have been reached by use of the candlepower in the single direction for which we had shown the factor to be practically constant.

2. PRESSURE OF GAS

The effect of the variation of pressure on the operation of mantle lamps was studied by keeping all other variable conditions as constant as possible and making a series of photometric observations with the supply to the lamp at various pressures. In the tests of a particular lamp the quality of gas was kept uniform by supplying the lamp from a small holder containing about 30 cubic feet of gas, the quality of which had been determined. Each lamp was tested at three adjustments, namely, the positions of the gas adjustment screw (air shutter open) giving maximum candlepower as determined by a photometer, at 2 inches, 3 inches, and 5 inches pressure, respectively. After adjusting the lamp to such maximum candlepower at one of these pressures, the pressure of the supply was varied by steps of one-half or 1 inch from the lowest to the highest pressure under which the lamp would probably be operated in general service. The extreme range of pressure was from one-half to 8 inches for each gas pressure, the candlepower of the lamp and the rate of gas consumption, as well as any peculiarities or irregularities of operation, were observed.

The results of one such series of operations (designated as series 1) are shown graphically in the typical curves of Fig. 4. Since the tests of the various lamps were made on different days, the data obtained from one lamp are not to be compared with the data from another lamp, so far as absolute values are concerned. The various curves for each lamp are, however, comparable and show the shapes of curves typical of each lamp.

The more important conclusions regarding the effects of pressure changes upon the operation of the various lamps tested are as follows:

(*a*) The lower the pressure at which a lamp is adjusted to maximum candlepower, the wider is the opening of the gas adjusting valve, and consequently the greater is the gas consumption at any given pressure.

(*b*) For any adjustment of a lamp, the following results are obtained with changes of the pressure of the gas supplied (from the lowest pressure at which the lamp will remain lighted):

1. The gas consumption is roughly proportional to the square root of the pressure.

2. The efficiency increases up to a maximum with increasing pressure, after which it decreases with further increase of pressure.

3. The candlepower increases with increasing pressure up to and beyond the pressure for the maximum efficiency until a maximum candlepower is obtained, after which the candlepower decreases with a further increase of pressure. However, with

FIG. 4.—*Effect of gas pressure variation upon the efficiency, gas consumption, and candlepower of various lamps*

some of the lamps tested it was not practicable to increase the pressure sufficiently to reach a true maximum of candlepower; this was especially notable with the upright-mantle lamp and to a lesser degree with the C. E-Z lamp.

(*c*) The lower the pressure at which a lamp is adjusted to give maximum candlepower, the greater is the opening of the gas-

adjusting valve, the larger is the gas consumption at a given pressure, and the nearer to each other are the pressures for production of maximum efficiency and maximum candlepower.

(*d*) When clean and with the air shutters wide open, none of the lamps show any tendency to carbon the mantles under any of the pressure conditions tried.

(*e*) Regardless of the pressure at which the lamp has been adjusted to give maximum candlepower, the maximum efficiency is almost invariably found at pressures between 2 and 4 inches.

3. GAS AND AIR ADJUSTMENTS

As has already been explained, in comparing results obtained with different gases at a given pressure two definite conditions were used, one being the condition which gave the highest candlepower attainable with the particular lamp and the other that which gave the highest efficiency. In order to obtain these conditions the flow of gas was varied step by step by means of the adjusting device provided in all the lamps, and then (in those lamps which had variable air ports) at each setting of the gas orifice the air ports were set by trial at the position which gave the best performance. The typical curves shown in Fig. 7 were obtained in this way, and similar curves were made for all other comparisons of different gases.

This procedure amounted to a study of the effects of gas and air adjustment under all the variations of other conditions used, but to discuss these effects in detail would require more space than it is desirable to give, and consequently only the results obtained at the maxima of candlepower and of efficiency have been considered.

In plotting these curves the rate of consumption of gas was taken as the basic variable, and as this was regulated by the position of a screw of some kind in each lamp, it is of some interest to show how the consumption varied with position of the screw. The results of a series of observations made for this purpose are shown in the curves of Fig. 5. In making these observations the gas pressure, gas quality, and air-shutter position were kept constant, while the position of the gas screw was varied. At each screw position the candlepower and rate of gas consumption were determined.

It will be noted that in only one case was there anything approaching proportionality of apparent opening to the real opening as shown by the rate of flow of gas. In two of the lamps the orifice was practically wide open when the screw had been moved

over about half of its range, and consequently turning it farther had no effect. In both of these lamps (the Reflex and the Junior) this wide-open position gave the best performance, but this would not be true for richer gases.

The sharply defined maximum in the efficiency curve for the C. E-Z lamp is corroborated by other measurements on this type of lamp.

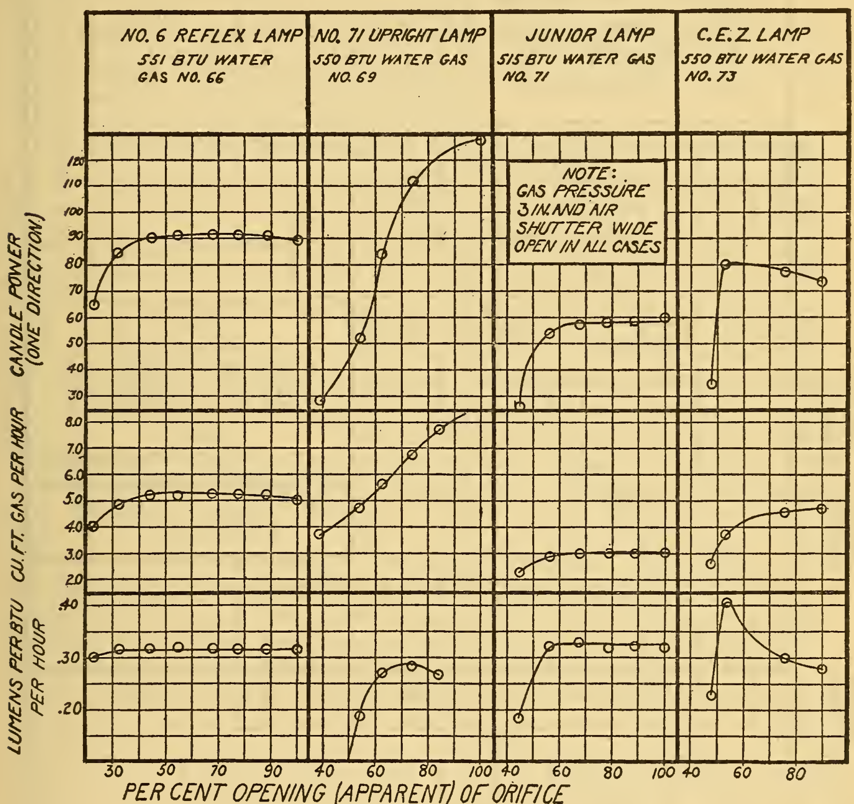

FIG. 5.—*Effects of gas adjustment upon candlepower, gas consumption, and efficiency of various lamps*

In this, as in the preceding series, the absolute values obtained with the different lamps are not comparable, because the lamps were tested on different days and with different gases.

The effects of changing the air adjustment depend, of course, on the other conditions of operation. It was usually found that with small gas consumption, and particularly with the leaner gases, the best performance was obtained with the air ports closed as far as was possible. In some such cases it was necessary to

close the ports to prevent the flame from flashing back into the mixing tube. With higher consumptions and richer gases the best performance was obtained with air ports wide open; in fact, this was true over the greater part of the range of desirable operating conditions. At fairly high consumptions, even of lean gases,

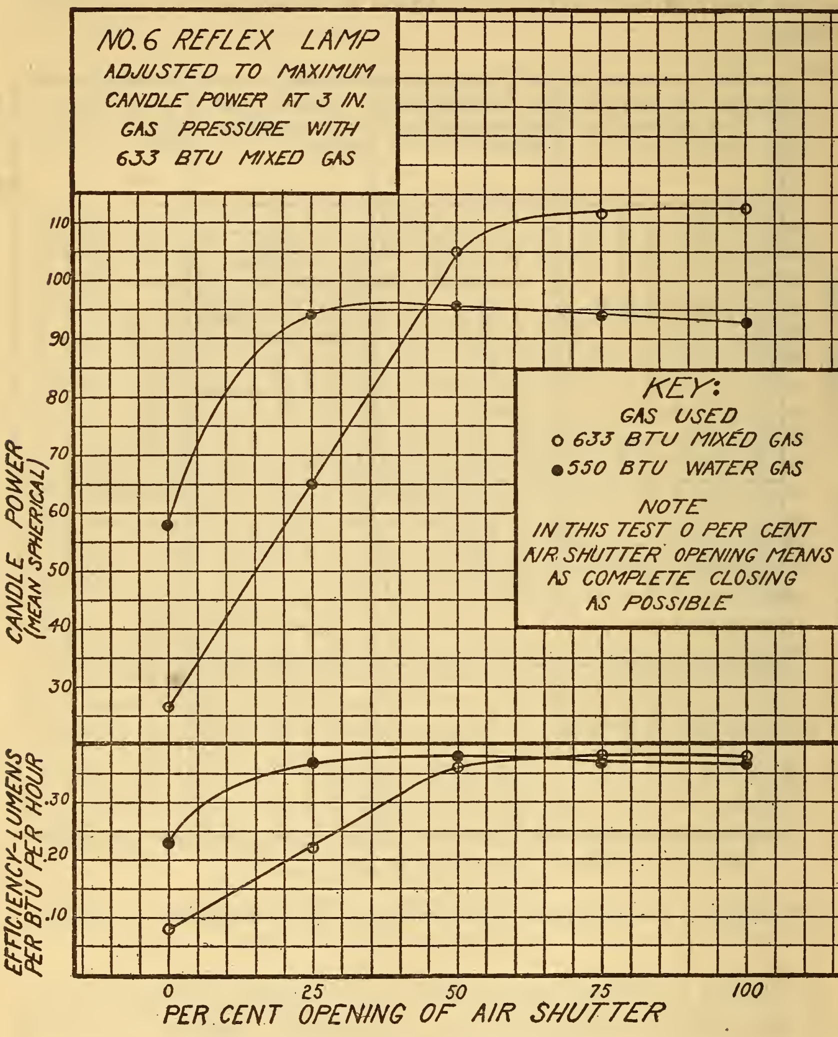

FIG. 6.—*Effect of air shutter position*

there is very little to be gained by closing the air ports, while under some conditions closing them may greatly decrease the efficiency. The air ports should nearly always be wide open.

To illustrate the effects of air adjustment there are plotted in Fig. 6 two series of measurements on a Reflex lamp in which

the gas pressure and gas orifice were kept constant, while the air shutter was set at different positions. The lamp was initially adjusted to give maximum candlepower with mixed gas of 633 Btu per cubic foot with the air shutter wide open, and no change was made except in the position of the air shutter. The consumption was therefore constant with each gas, being 4.7 cubic feet per hour of the 633 Btu mixed gas and 4.6 of the 550 Btu water gas. From relations between consumption, maximum candlepower, and maximum efficiency which will be discussed later, it may be inferred that the initial adjustment gave very close to maximum efficiency for the 550 Btu water gas.

The lamp having been adjusted for a rather high consumption, the candlepower and efficiency fell off rapidly as the air shutter was closed when burning the richer gas, but with the leaner gas there was a slight improvement obtained by partly closing off the air.

In general, the greatest excess of air that can be obtained with any of these lamps has an effect much less serious than the effect of even a slight deficiency of air. Consequently with the leaner gases, which require less air, the lamps are less sensitive to air-shutter adjustments.

Any maladjustment of air shutter with rich gas almost invariably gives too little primary air and hence produces a loss in efficiency and a likelihood of carboned mantles. With lean gases the air shutter can often be nearly closed without great loss of efficiency and there seems to be less tendency to carbon the mantle. The difficulty with the leaner gas is that there is greater tendency of the lamps to back fire and burn in the mixing tube because the shutter is too wide open. However, this has been regarded as a less serious difficulty than that of carboning the mantles because it is a condition that is at once noted by the user and is therefore likely to be corrected promptly by partly closing the air shutter.

4. FITTERS' ADJUSTMENT

In adjusting a lamp for service it is usual to regulate the gas supply so that the maximum candlepower, as judged by the eye, is obtained. However, one very large gas company in the United States has adopted a slightly different adjustment for the lamps which it maintains. The fitters employed by this company are instructed to adjust the gas supply until the candlepower is apparently at a maximum and then to decrease the gas supply

until a slight but distinct diminution in the candlepower is effected. The object in so adjusting is to diminish the probability of carboning the mantles. As will be noted from Fig. 4, the point of maximum efficiency for a given lamp occurs at a lower gas consumption than the point of maximum candlepower, therefore in reducing the gas consumption slightly below the maximum-candlepower point the lamp is actually brought nearer to its point of maximum efficiency. In the course of our work a number of fitters' adjustments were made by several observers according to the instructions given above. It was found that while there was considerable variation among the various adjustments made, the average of all such adjustments on a lamp was very close to the point of maximum efficiency.

From a study of the pressure-efficiency curves (Fig. 4), it will be noted that this slight decrease in the gas consumption may have still another helpful effect. This is true since such a change in adjustment will assist in correcting the effects of changes in gas pressure in cases where the pressure at which the lamp is operated is higher than the pressure at time of adjustment, a condition not infrequently found especially in cities where many lamps are periodically visited by the gas company or lamp companies for cleaning or adjustment.

5. KIND OF GAS

In making comparisons of the operation of a lamp with various gases all conditions other than the quality of the gas supply and the adjustment of the lamp were kept as constant as possible. In order to facilitate this, comparison was made only between results obtained on the same day and using the same mantle, glassware, and measuring apparatus. Observations of barometric pressure, humidity, and temperature were made with sufficient frequency so that any marked change in conditions would be noticed and the proper corrections applied. In comparing two gases the pressure at the burner was kept constant throughout the test, but the adjustments of the gas supply and the air shutter were altered to ascertain the most favorable condition for each gas. A set of photometric readings was taken at each adjustment and the rate of gas consumption was determined. From these data the efficiency of the lamp in lumens per Btu per hour was calculated. From the values obtained the candlepower and efficiency curves were plotted in the typical form. (See Fig. 7.) From these curves for each run the candlepower, efficiency, and consumption of gas could be noted for the points of maximum

candlepower and of maximum efficiency. Comparisons of gases were made between the observations of a single day at these two points.

Such comparisons were made between lean water gas and the city supply of rich mixed gas, between lean water gas and lean coal gas, and between the city supply and a specially enriched gas prepared by introducing benzol vapor into the city gas (changing the gas from 15 candles and 630 Btu to 21 candles and 650 Btu or

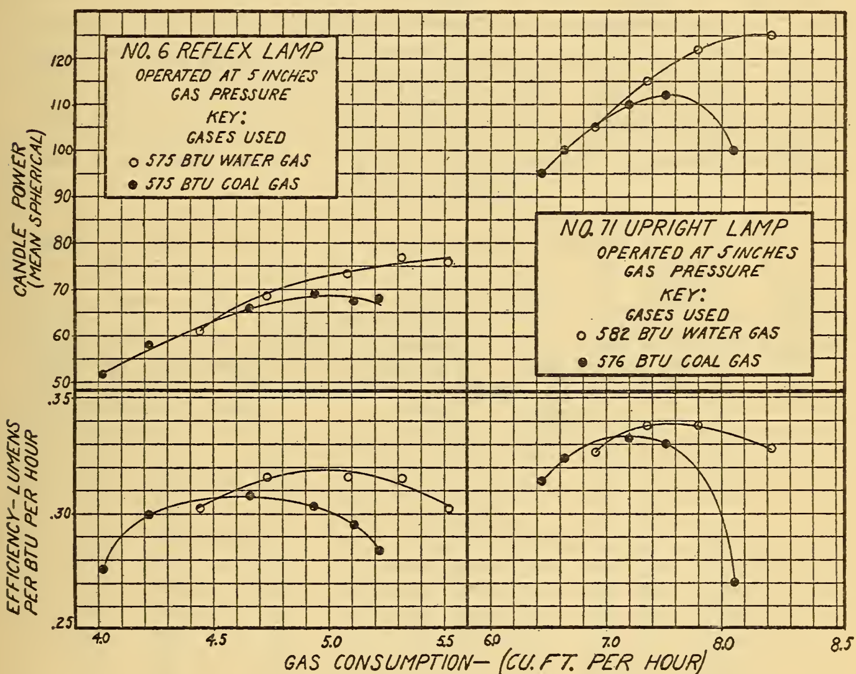

FIG. 7.—*Comparative operation of lamps with coal gas and water gas of about the same total heating value*

higher). The nature of these gases can be seen by consulting the summary of analyses in the appendix to this paper. (See p. 48.)

The comparison of lean water gas and the city supply showed the influence of the differences in total heating value for gases of rather similar composition. The benzolized gas was used to ascertain the influence of this hydrocarbon vapor upon the efficiency of the lamp. The influence of the different proportions of hydrogen, carbon monoxide, and methane, in coal gas as compared with water gas, is shown by the third series of comparisons.

Table 5 presents the results of these comparisons between the lean water gases and the city gas which was largely water gas.

Only the data for the points of maximum candlepower and of maximum efficiency are presented, since comparisons are feasible only under these two conditions. The results for candlepower consumption of gas, and efficiency are taken from curves like those of Fig. 7. The efficiency change per 100 Btu decrease in heating value per cubic foot is computed by dividing 100 times the difference in efficiency of the two gases of each pair by the difference in the heating value of the gases. When the value is plus, it indicates an advantage in luminous efficiency for the leaner gas, when minus, a disadvantage. In considering these data and those of the two tables following, comparison should be made only between the two tests of each pair; comparison between the results for different lamps should not be made except in a very general way.

TABLE 5.—Influence of Heating Value of Water Gas Upon Efficiency in Use

UPRIGHT LAMPS

Test No.	Pressure of gas, inches.	Gas No.	Heating value of gas, Btu per cubic foot	Adjusted to maximum candlepower					Adjusted to maximum efficiency				
				Mean spherical candlepower	Gas consumption		Efficiency lumens per Btu per hour	Change in lumens per 100 Btu	Mean spherical candlepower	Gas consumption		Efficiency lumens per Btu per hour	Change in lumens per 100 Btu
					Cubic feet per hour	Btu per hour				Cubic feet per hour	Btu per hour		
1	3	104	686	81	5.7	3910	0.255	....	78	5.4	3700	0.265	....
		105	570	93	7.1	4050	.290	+0.03	92	6.8	3880	.295	+0.03
2	3	103	629	81	5.9	3710	.275	....	80	5.7	3580	.285	....
		102	573	96	7.2	4070	.295	+ .04	95	7.0	4010	.300	+ .03
[a]3	3	104	686	69	4.3	2950	.295	....	68	4.2	2880	.305	....
		105	570	72	5.1	2910	.315	+ .02	70	4.8	2740	.320	+ .01
[a]4	3	103	629	71	6.2	3900	.220	....	70	6.0	3770	.235	....
		102	573	74	7.0	4010	.230	+ 02	74	6.6	3780	.240	+ .01
[a]5	3	103	629	103	6.1	3840	335	....	96	5.7	3580	.340	....
		102	573	[b]104	7.2	4130	[b]315	− .04	99	6.3	3610	.340	.00
[c]6	2	12	663	78	6.5	4310	.230	....	74	5.8	3840	.245	....
		15	548	90	7.8	4270	.265	+ .03	89	7.5	4110	.275	+ .02
[c]7	2	63	648	73	5.6	3630	.260	....	68	4.8	3110	.275	....
		77	548	[b]69	5.6	3070	[b].285	+ .03	[b]69	5.6	3070	[b].285	+ .01
[c]8	3	14	670	94	6.5	4360	.245	....	86	5.7	3820	.285	....
		15	548	109	7.8	4270	.255	+ .01	98	7.5	4110	.280	.00
[c]9	3	63	648	90	5.7	3690	.310	....	87	5.4	3500	.315	....
		77	548	[b]96	6.8	3730	[b].325	+ .02	95	6.7	3670	.325	+ .01
[c]10	5	......	666	111	8.5	5660	.245	....	102	6.6	4390	.290	....
		15	548	132	10.1	5540	.300	+ .05	129	9.5	5200	.310	+ .02
[c]11	5	74	631	113	7.8	4920	.290	....	106	6.8	4290	.310	....
		73	550	127	9.5	5220	.305	+ .02	121	8.7	4790	.315	+ .01
Maximum values.........				132	10.1	5660	.335	+ .05	129	9.5	5200	.340	+ .03
Minimum values.........				69	4.3	2910	.220	− .04	68	4.2	2740	.235	.00
Average...............				87	6.4	4100	.275	+ .02	88	6.3	3792	.292	+ .01

[a] Cheaper grades of lamps used.

[b] This value was the maximum obtainable under the conditions of the experiment, but the value does not represent a true maximum.

[c] Readings made in sphere.

TABLE 5.—Influence of Heating Value of Water Gas Upon Efficiency in Use—Continued

JUNIOR LAMPS

Test No.	Pressure of gas, inches	Gas No.	Heating value of gas, Btu per cubic foot	Adjusted to maximum candlepower: Mean spherical candlepower	Adjusted to maximum candlepower: Gas consumption, Cubic feet per hour	Adjusted to maximum candlepower: Gas consumption, Btu per hour	Adjusted to maximum candlepower: Efficiency lumens per Btu per hour	Adjusted to maximum candlepower: Change in lumens per 100 Btu	Adjusted to maximum efficiency: Mean spherical candlepower	Adjusted to maximum efficiency: Gas consumption, Cubic feet per hour	Adjusted to maximum efficiency: Gas consumption, Btu per hour	Adjusted to maximum efficiency: Efficiency lumens per Btu per hour	Adjusted to maximum efficiency: Change in lumens per 100 Btu
12	3	106	650	45	2.4	1560	0.355	....	43	2.3	1490	0.365	....
		107	554	46	2.9	1610	.355	0.00	45	2.7	1500	.360	−0.01
[a] 13	3	106	651	37	2.2	1430	.320	....	35	2.0	1300	.340	....
		107	554	40	2.6	1440	.345	+ .03	37	2.4	1330	.355	+ .02
[a] 14	3	106	650	38	2.2	1430	.340	....	38	2.1	1360	.350	....
		107	554	42	2.9	1610	.330	− .01	41	2.6	1440	.360	+ .01
[b] 15	2	[a] 77	680	39	2.2	1500	.330	....	37	2.0	1360	.345	....
		77	548	38	2.5	1370	.380	+ .04	37	2.5	1370	.385	+ .03
[b] 16	3	......	647	41	2.4	1550	.320	....	38	2.2	1420	.330	....
		21	530	38	3.0	1590	.310	− .01	37	2.9	1540	.315	− .01
[b] 17	3	[a] 75	636	45	2.6	1650	.330	....	43	2.4	1530	.365	....
		77	548	47	2.5	1370	.345	+ .02	46	2.4	1320	.365	.00
[b] 18	5	75	624	49	3.1	1930	.325	....	44	2.6	1620	.345	....
		77	548	51	3.7	2030	.325	.00	48	3.3	1810	.335	− .01
Maximum values..........				51	3.7	2030	.380	+ .03	48	3.3	1810	.385	+ .05
Minimum vaues...........				37	2.2	1370	.310	− .01	35	2.0	1300	.330	− .01
Average.................				31	2.7	1580	.336	+ .01	41	2.5	1460	.355	+ .00

C. E-Z LAMPS

Test No.	Pressure of gas, inches	Gas No.	Heating value of gas, Btu per cubic foot	Adjusted to maximum candlepower: Mean spherical candlepower	Adjusted to maximum candlepower: Gas consumption, Cubic feet per hour	Adjusted to maximum candlepower: Gas consumption, Btu per hour	Adjusted to maximum candlepower: Efficiency lumens per Btu per hour	Adjusted to maximum candlepower: Change in lumens per 100 Btu	Adjusted to maximum efficiency: Mean spherical candlepower	Adjusted to maximum efficiency: Gas consumption, Cubic feet per hour	Adjusted to maximum efficiency: Gas consumption, Btu per hour	Adjusted to maximum efficiency: Efficiency lumens per Btu per hour	Adjusted to maximum efficiency: Change in lumens per 100 Btu
21	3	98	646	62	3.2	2070	0.390	+0.02	62	3.0	1940	0.405	....
		97	537	69	3.9	2090	.410	....	66	3.7	1990	.420	+0.01
22	3	98	646	63	2.8	1810	.425	+ .03	62	2.6	1680	.455	....
		97	537	76	4.0	2150	.455	....	73	3.6	1930	.485	+ .03
23	3	98	646	65	3.1	2000	.415	.00	61	2.9	1870	.435	− .01
		97	537	72	4.0	2150	.415	....	67	3.7	1990	.420	....
[b] 24	2	24	640	52	3.1	1980	.340	....	49	2.7	1730	.355	− .01
		23	544	58	4.0	2170	.335	− .01	55	3.6	1960	.350	....
[b] 25	2	64	618	51	2.9	1790	.365	− .01	49	2.6	1610	.390	− .02
		81	544	60	3.9	2120	.360	....	55	3.4	1850	.375	....
[b] 26	3	24	640	60	3.4	2180	.345	.00	54	2.9	1860	.375	− .02
		23	544	59	4.0	2180	.345	....	53	3.5	1900	.355	....
[b] 27	3	64	618	64	3.4	2100	.380	− .04	56	2.9	1790	.385	.00
		81	544	67	4.5	2450	.350	....	61	3.7	2010	.385	....
[b] 28	5	26	652	69	3.9	2540	.340	− .01	64	3.2	2090	.385	− .01
		23	544	77	5.5	2990	.325	....	70	4.4	2390	.370	....
[b] 29	5	72	631	73	4.1	2590	.355	− .01	62	3.2	2020	.385	+ .01
		73	550	80	5.2	2860	.345	....	70	4.0	2200	.395	....
Maximum value..........				80	5.5	2990	.455	+ .03	70	4.4	2390	.485	+ .03
Minimum value..........				51	2.8	1790	.325	− .04	49	2.6	1610	.350	− .02
Average................				66	3.8	2234	.372	.00	60	3.3	1989	.395	.00

[a] Cheaper grades of lamps used. [b] Readings made in sphere.

TABLE 5.—Influence of Heating Value of Water Gas Upon Efficiency in Use—Continued

REFLEX AND INVERTED LAMPS

Test No.	Pressure of gas, inches.	Gas No.	Heating value of gas, Btu per cubic foot	Adjusted to maximum candlepower					Adjusted to maximum efficiency				
				Mean spherical candlepower	Gas consumption		Efficiency lumens per Btu per hour	Change in lumens per 100 Btu	Mean spherical candlepower	Gas consumption		Efficiency lumens per Btu per hour	Change in lumens per 100 Btu
					Cubic feet per hour	Btu per hour				Cubic feet per hour	Btu per hour		
30	3	91	663	87	4.0	2650	0.420	−0.02	84	3.7	2450	0.425	−0.02
		92	580	[a] 87	4.6	2670	.405	....	87	4.6	2670	.405	....
31	3	98	646	[a] 86	4.5	2900	.370	.00	80	4.0	2580	.390	− .09
		97	537	[a] 74	4.6	2470	.375	....	[a] 74	4.6	2470	[a] .380	....
32	3	......	650	[a] 82	4.0	2620	.385	− .04	79	3.9	2540	.400	− .09
		87	566	[a] 70	4.4	2490	.350	....	67	4.3	2430	.380	....
33	3	91	663	[a] 81	3.8	2520	.405	− .07	80	3.7	2550	.410	− .05
		92	580	[a] 70	4.3	2490	.365	....	[a] 70	4.3	2490	[a] .365	....
34	3	90	654	77	4.4	2880	.335	− .04	69	3.8	2480	.365	+ .05
		87	566	[a] 77	4.8	2720	.300	....	72	4.4	2490	.370	....
35	3	91	663	[a] 77	4.1	2720	.355	− .01	71	3.6	2390	.370	− .01
		92	580	[a] 79	5.0	2900	.345	....	74	4.5	2610	.360	....
36	3	91	663	[a] 87	4.8	3180	.335	+ .06	80	4.5	2980	.345	+ .04
		93	574	[a] 85	4.8	2760	.385	....	81	4.6	2640	.385	....
37	5	101	658	87	5.0	3290	.330	+ .03	79	4.1	2700	.385	− .01
		100	567	90	5.8	3290	.355	....	84	5.0	2830	.375	....
38	5	106	651	89	4.8	3120	.360	+ .02	75	4.3	2800	.375	+ .07
		107	554	94	5.6	3100	.380	....	89	5.0	2770	.400	....
39	5	108	650	95	4.9	3190	.375	+ .03	88	4.1	2660	.405	+ .02
		109	561	98	5.4	3030	.405	....	93	5.0	2810	.420	....
[b] 40	3	98	646	64	3.7	2390	.335	− .02	61	3.4	2200	.340	− .01
		97	537	61	4.6	2470	.310	....	57	4.1	2200	.325	....
[b] 41	5	101	658	66	4.2	2760	.300	.00	61	3.5	2300	.335	− .01
		100	567	66	5.0	2830	.300	....	61	4.2	2380	.325	....
[c] 42	2	68	640	[a] 72	3.9	2490	.370	− .03	70	3.8	2430	.370	− .03
		66	553	[a] 58	3.8	2100	.345	....	[a] 58	3.8	2100	[a] .345	....
[c] 43	3	18	651	71	4.6	2990	.305	+ .03	65	3.8	2470	.335	.00
		19	537	[a] 71	4.9	2630	.335	....	69	4.8	2580	.335	....
[c] 44	3	68	640	[a] 81	4.7	3010	.375	− .01	74	3.9	2490	.370	+ .01
		66	553	[a] 78	4.8	2650	.370	....	75	4.5	2490	.380	....
[c] 45	5	18	651	78	5.0	3250	.300	+ .01	72	4.2	2730	.335	.00
		19	537	86	6.4	3440	.315	....	77	5.3	2840	.340	....
[c] 46	5	68	639	87	5.0	3190	.340	+ .01	81	4.3	2750	.370	+ .01
		69	550	90	6.0	3300	.345	....	85	5.1	2800	.380	....
[c] 47	2	80	641	[a] 43	3.7	2370	.225	+ .07	40	3.3	2120	.245	+ .05
		79	567	53	4.3	2440	.275	....	51	4.0	2270	.285	....
[c] 48	3	71	636	[a] 62	3.9	2480	.310	− .02	[a] 62	3.9	2480	.310	.00
		80	590	70	5.0	2950	.300	....	66	4.6	2720	.310	....
Maximum value..........				98	6.4	3440	.420	+ .07	93	5.3	2980	.425	+ .07
Minimum value..........				43	3.7	2100	.225	− .04	40	3.3	2100	.245	− .09
Average..............				74	4.7	2810	.344	.00	73	4.4	2565	.364	.00

[a] This value was the maximum obtainable under the conditions of the experiment, but the value does not represent a true maximum.

[b] Cheaper grades of lamps used.

[c] Made in sphere.

Some of the comparisons, as indicated in footnotes, were made in the integrating sphere; the other tests were made with the simple photometer at the appropriate angle, but are computed to show the mean spherical candlepower corrected for variations in humidity to a standard condition of 8 liters of water vapor per cubic meter of air (equivalent to 0.8 per cent water vapor by volume).

TABLE 6.—Comparison of Efficiencies of City Gas and Benzolized Gas

REFLEX LAMPS

Test No.	Pressure of gas, inches	Gas No.	Heating value of gas, Btu per cubic foot	Adjusted to maximum candlepower					Adjusted to maximum efficiency				
				Mean spherical candlepower	Gas consumption: Cubic feet per hour	Gas consumption: Btu per hour	Efficiency lumens per Btu per hour	Change in lumens per 100 Btu	Mean spherical candlepower	Gas consumption: Cubic feet per hour	Gas consumption: Btu per hour	Efficiency lumens per Btu per hour	Change in lumens per 100 Btu
[a] 49	5	121	[b]B 651	84	4.3	2800	0.375	....	83	4.2	2730	0.375	....
		122	631	84	4.8	3030	.345	−0.15	79	4.3	2720	.370	−0.03
51	3	111	B 726	66	3.5	2540	.330	....	62	3.3	2390	.335	....
		111	670	70	3.8	2550	.345	+ .03	64	3.4	2280	.355	+ .04
UPRIGHT LAMPS													
[a] 50	3	121	B 651	86	5.5	3580	0.300	....	83	5.2	3380	0.310	....
		123	633	85	5.8	3670	.295	−0.03	82	5.3	3290	.305	−0.03
[a] 52	5	121	B 651	107	6.5	4230	.315	....	98	5.8	3780	.330	....
		123	633	110	6.5	4110	.325	+ .06	106	6.1	3860	.330	.00
53	2	115	B 737	86	5.4	3980	.265	....	80	4.8	3540	.285	....
		116	663	82	6.5	4310	.240	− .03	79	5.7	3780	.255	− .04
54	3	113	B 724	100	6.9	5000	.290	....	90	5.0	3620	.310	....
		113	670	99	6.5	4360	.285	− .01	90	5.1	3420	.300	− .02
55	5	......	B 724	112	6.8	4920	.310	....	112	5.9	4270	.330	....
		114	670	118	8.5	5700	.260	− .09	108	6.6	4420	.310	− .04
56	5	115	B 737	113	6.8	5010	.280	....	108	5.9	4350	.310	....
		116	663	114	8.6	5700	.250	− .04	106	6.6	4370	.305	− .01

[a] These runs are of doubtful significance on account of the small differences in the heating values of the gases compared; therefore results in these tables have not been averaged.
[b] B=Benzolized gas.

The use of cheaper grades of lamps or of lamps of different construction than those employed in most of the comparisons is indicated in the footnotes.

Where the curves did not reach a true maximum of candlepower or efficiency within the range of consumption which could be obtained with the pressure in use, this fact is noted in the table. The value given in such cases represents the maximum attained. In these cases the comparisons of efficiency are, of course, some-

what less significant than otherwise. The reason that maximum candlepower or efficiency was not reached is believed to have been small amounts of dust in the gas orifice; but in a few cases it was the result of low pressure (tests 7 and 42) or of peculiarities of the individual lamps used (tests 5, 47, and 48).

TABLE 7.—Comparison of Efficiencies of Coal Gas and Water Gas of Approximately Equal Total Heating Value

REFLEX LAMPS

Test No.	Pressure of gas, inches	Gas No.	Heating value of gas, Btu per cubic foot	Adjusted to maximum candlepower					Adjusted to maximum efficiency				
				Mean spherical candlepower	Gas consumption: Cubic feet per hour	Gas consumption: Btu per hour	Efficiency lumens per Btu per hour	Efficiency change	Mean spherical candlepower	Gas consumption: Cubic feet per hour	Gas consumption: Btu per hour	Efficiency lumens per Btu per hour	Efficiency change
								Per ct.					Per ct.
57	3	117	[a]C 576	59	4.5	2590	0.280	....	58	4.4	2450	0.285	....
		118	[b]W 575	[c]56	4.4	2530	.280	0	[c]56	4.4	2530	.280	1.7
58	5	117	C 576	72	5.0	2870	.315	....	68	4.6	2650	.320	....
		118	W 575	79	5.4	3100	.325	3.2	76	5.0	2870	.335	4.7
59	5	120	C 582	69	4.9	2850	.305	....	66	4.6	2680	.315	....
		118	W 568	[c]76	5.0	2840	.305	0	65	4.5	2560	.320	1.6
Maximum value				79	5.4	3100	.325	3.2	76	5.0	2870	.335	4.7
Minimum value				56	4.4	2530	.280	0	56	4.4	2450	.280	1.6
Average				68	4.9	2800	.300	1.0	65	4.6	2620	.310	2.7

UPRIGHT LAMPS

Test No.	Pressure of gas, inches	Gas No.	Heating value of gas, Btu per cubic foot	Mean spherical candlepower	Cubic feet per hour	Btu per hour	Efficiency lumens per Btu per hour	Efficiency change	Mean spherical candlepower	Cubic feet per hour	Btu per hour	Efficiency lumens per Btu per hour	Efficiency change
60	3	117	C 576	91	6.1	3510	0.310	....	87	5.3	3050	0.320	....
		116	W 582	98	6.7	3900	.315	1.6	96	6.3	3670	.325	1.5
61	5	117	C 576	107	7.5	4320	.315	....	106	7.2	4140	.320	....
		116	W 582	123	8.4	4890	.315	0	116	7.6	4420	.330	3.1
Maximum value				123	8.4	4890	.315	1.6	116	7.6	4420	.330	3.1
Minimum value				91	6.1	3510	.310	0	87	5.3	3050	.320	1.5
Average				105	7.2	4150	.315	.8	101	6.6	3870	.325	2.3

[a] C=coal gas.

[b] W=water gas.

[c] This value was the maximum obtainable under the conditions of the experiment, but the value does not represent a true maximum.

Table 6 gives corresponding data for comparisons between city gas and benzolized gas; and Table 7 a comparison between coal gas and water gas of about the same total heating values. However, in Table 7 the differences in efficiency shown are absolute differences; that is, are not computed per 100 Btu change in heating value. The differences marked plus represent an advantage for water gas; those marked minus, an advantage for coal gas.

Some measurements with natural gas from southern Ohio, which were made shortly before this investigation was begun, are also included here as Table 8. The total heating value of the natural gas was 1120 Btu per cubic foot; its composition is given in the appendix. It was compared with a mixed gas of about 625 Btu per cubic foot.

TABLE 8.—Comparison of Natural Gas with Manufactured City Gas

[Heating Values, 1120 and 625 Btu per cubic foot. Pressure, 7 and 3 Inches of Water.]

Pressure of gas, inches	Heating value of gas, Btu per cubic foot	Adjusted to maximum candlepower					Adjusted to maximum efficiency				
		Mean spherical candlepower	Gas consumption		Efficiency lumens per Btu per hour	Per cent efficiency	Mean spherical candlepower	Gas consumption		Efficiency lumens per Btu per hour	Change in lumens per 100 Btu
			Cubic feet per hour	Btu per hour				Cubic feet per hour	Btu per hour		
REFLEX LAMPS											
7	[a]N 1120	63	2.4	269	0.295	0.014	61	2.3	258	0.300	0.017
3	625	80	4.7	294	.340	....	67	4.3	269	.360	....
UPRIGHT LAMPS											
7	N 1120	66	3.2	358	0.230	0.021	64	2.9	325	0.250	0.023
3	625	68	6.0	375	.295	....	80	5.0	313	.320	....
JUNIOR LAMPS											
7	N 1120	24	1.2	135	0.225	0.025	23	1.1	123	0.230	0.030
3	625	36	2.4	150	.295	....	35	2.1	131	.330	....
C. E-Z LAMPS											
7	N 1120	46	2.0	224	0.260	0.020	40	1.5	168	0.300	0.015
3	625	56	3.5	219	.320	....	49	2.8	175	.350	....

[a] N=Natural gas.

Between the natural gas and manufactured gas comparisons can not be made with conditions so closely similar as is done in comparing two kinds of gas which are more nearly alike. For example, instead of burning the two gases in succession in the same lamp, each gas must be burned in a lamp adapted to it. Moreover, the pressures used for tests, being like those commercially prevailing, are decidedly different for the two types of gas. In these tests, the gas was used at pressures which were considered to represent common practice; these were 7 inches of water (approximately 4 ounces per square inch) for the natural gas and 3 inches for the manufactured gas.

The data given in most cases represent measurements on a single lamp of each kind, but some of the results for manufactured gas are the averages for two or three lamps of measurements which were made within a few days of the time when the natural gas was tested. Exact conclusions can not be drawn from so small a number of measurements, but the degree of consistency of the results seems to justify the statement that in regular commercial lamps natural gas may be expected to give an efficiency (per heat unit) about 20 per cent lower than manufactured gas.

To summarize all the data on manufactured gas in a convenient form Tables 9 and 10 have been prepared, showing for the four styles of lamp the changes in efficiency expressed as percentages of the average efficiency. The following general conclusions are drawn from these data:

1. The upright lamps show a distinctly higher efficiency with the lean water gas than with the city gas, both at maximum-candlepower and maximum-efficiency adjustments; and the advantage is greater at maximum candlepower than at maximum efficiency.

2. The Junior lamps show a distinctly higher efficiency at maximum-candlepower adjustments with the lean gas than with the city gas; but at maximum-efficiency adjustments there is practically no difference between the efficiencies obtained.

TABLE 9.—Lean Water Gas versus City Gas

[Percentage increase in efficiency with 100 Btu per cubic foot decrease in heating value]

Lamp	Number of comparisons	Maximum-candlepower adjustment	Maximum-efficiency adjustment
		Per cent	Per cent
Upright	11	7	3
Inverted	19	0	0
Junior	7	3	0
C. E-Z	9	0	0

3. The inverted and C. E-Z lamps show no difference in efficiency, within the limits of experimental uncertainties, with the lean water gas and the city gas either at maximum-efficiency or maximum-candlepower adjustments.

4. The upright-mantle lamps show, so far as the tests are significant, a distinct advantage of the benzol-enriched gas, both at maximum-candlepower and maximum-efficiency adjustments. As will be seen from Table 6, an insufficient number of runs was

made to show conclusively whether the presence of considerable benzol in the city gas had any marked effect on the efficiency of the inverted-mantle type of lamps. On account of the small difference between the heating values of the gases used in test 49, the difference found is probably not significant. Test 51 shows an advantage of the leaner gas, but more tests would be necessary to confirm this.

5. With both upright and inverted mantle lamps at either maximum candlepower or maximum efficiency there is a distinct, but small, advantage of water gas over coal gas of the same total heating value, except in some cases at very low pressures (less than 2 inches), when lean water gas may not show as high efficiencies as rich water gas or lean coal gas on account of the inability of the lamp to pass sufficient of the lean water gas to attain a true maximum efficiency. This advantage of water gas over coal gas probably results largely from the smaller loss of heat in the products with water gas than with coal gas of the same total heating value. (The lower net heating value is also a result of this.) However, there are some differences in flame characteristics that result from difference in the proportions of hydrogen, carbon monoxide, and hydrocarbons, and these are perhaps fully as important as the differences in heat losses.[11] In this connection it is interesting to note that we have found a distinct indication of higher heat input at maximum efficiency or at maximum candlepower with water gas than with coal gas except in those tests where the true maximum adjustment was not reached. (See especially Fig. 7.)

TABLE 10.—Advantage of Lean Water Gas over Lean Coal Gas of Approximately Equal Total Heating Value

[Percentages refer to difference in efficiency, i. e., differences in lumens per Btu per hour in favor of the water gas]

Lamp	Number of comparisons	Maximum-candlepower adjustment	Maximum-efficiency adjustment
		Per cent	Per cent
Upright	2	1	2
Inverted	3	1	3

Greater ease of adjustment with lean gas than with rich gas is often claimed, but we have not been able to prove conclusively any such influence. There are distinct indications that the range

[11] The influcnee of these flame characteristics is being investigated further at this Bureau.

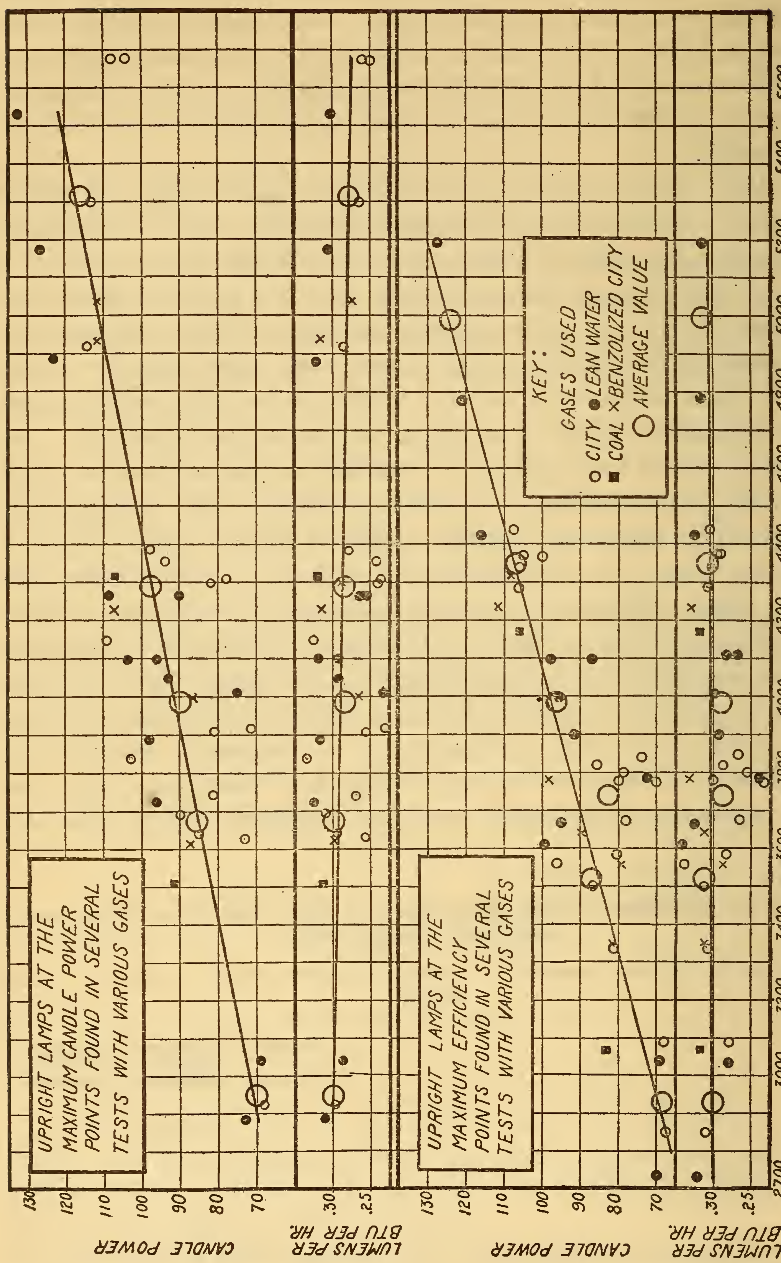

FIG. 8.—*Performance of various upright-mantle lamps with various gases at various rates of heat input*

of air-shutter adjustment is wider with lean gas (see preceding section) and somewhat less definite indication that near the point of maximum efficiency there is a wider range of gas rate for equally good efficiency. Beyond this point, however, we would not be justified in drawing any conclusion as to the advantages of leaner

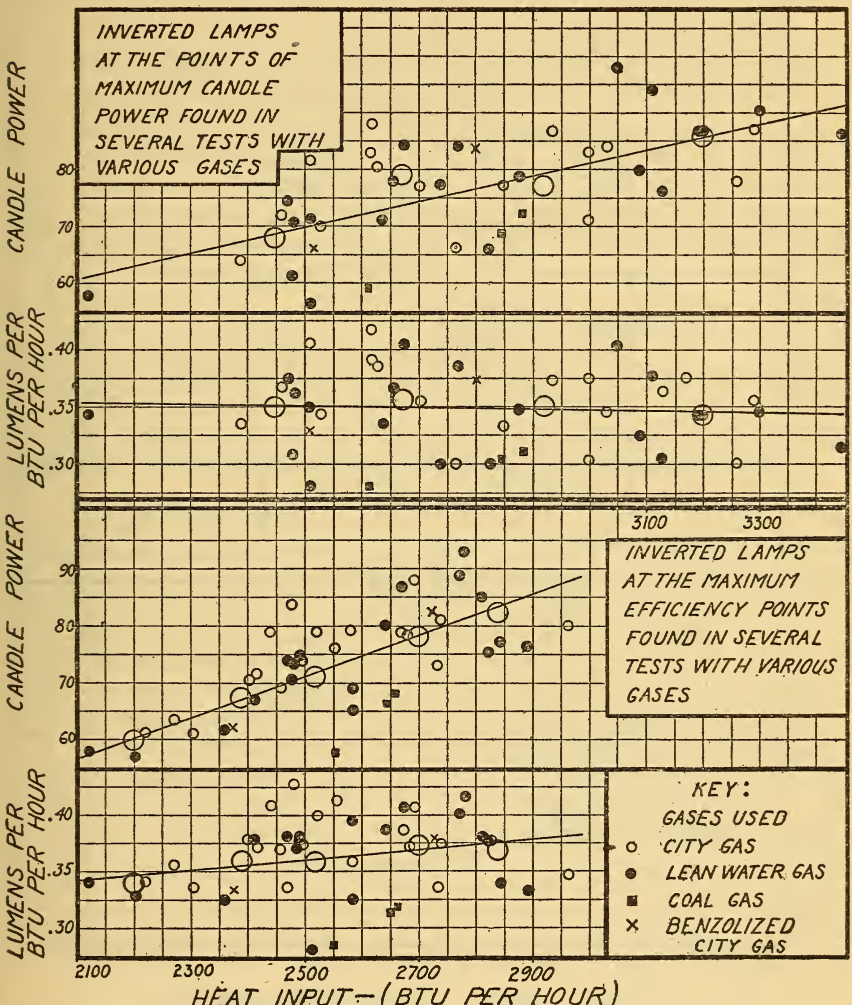

FIG. 9.—*Performance of inverted-mantle lamps with various gases at various rates of heat input*

gas. It was also noted that when operated on lean water gas with wide-open air shutters, the inverted-mantle and C. E-Z lamps become noisy at very low pressures and in a few cases back-fire. No noticeably greater tendency to carboning of mantles was observed with one quality of gas than with another, provided the

gas passages of the lamp were clear and the air shutters were wide open. This subject is discussed at greater length in a report on field inspections of mantles, which includes a summary of carboned mantles as evidence of this point.[12]

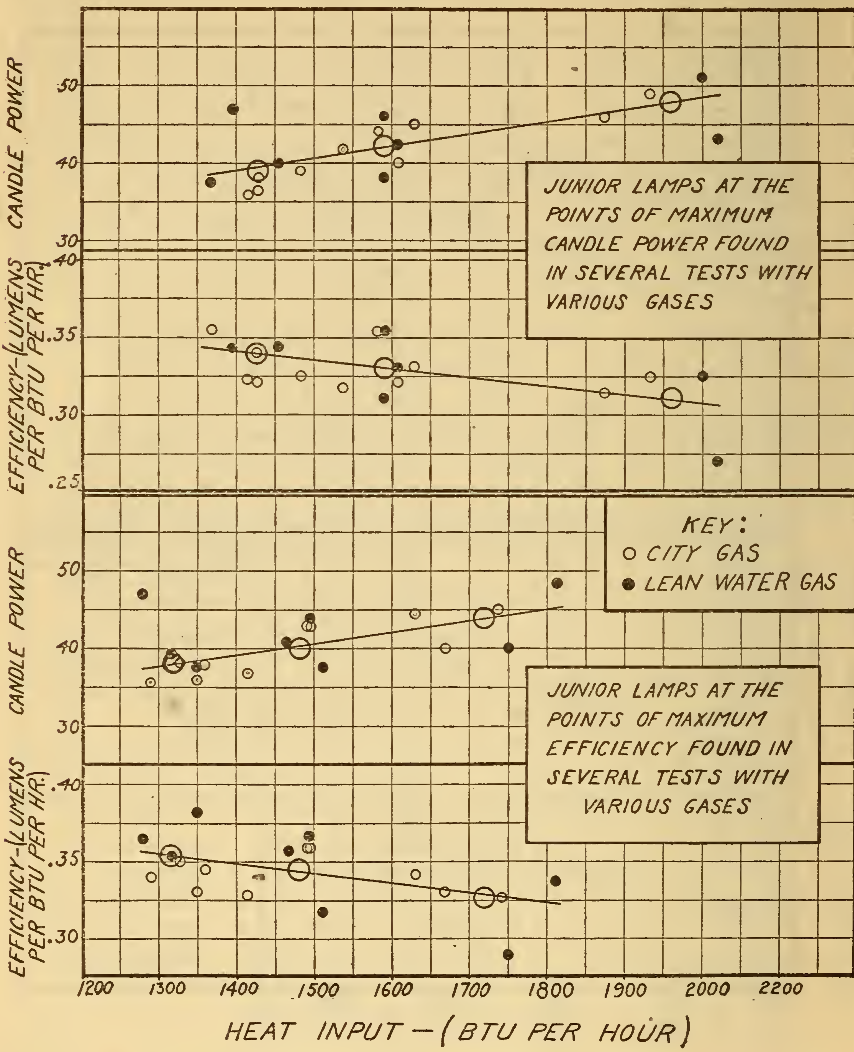

Fig. 10.—*Performance of Junior lamps with various gases at various rates of heat input*

A further study of the relation of candlepower and efficiency to the rate of heat input under conditions of maximum candlepower and maximum efficiency is shown in the curves of Figs. 8–11, which are plotted from the data of Tables 5–7, to show all

[12] Bureau of Standards, Technologic Paper No. 99, by R. S. McBride and C. E. Reinicker.

the maximum candlepower and efficiency values for all the gases tested. These values are from several lamps operated under various pressures and other conditions. The curves are so proportioned that the same percentage change in heat input is of practically the same apparent magnitude in the several figures.

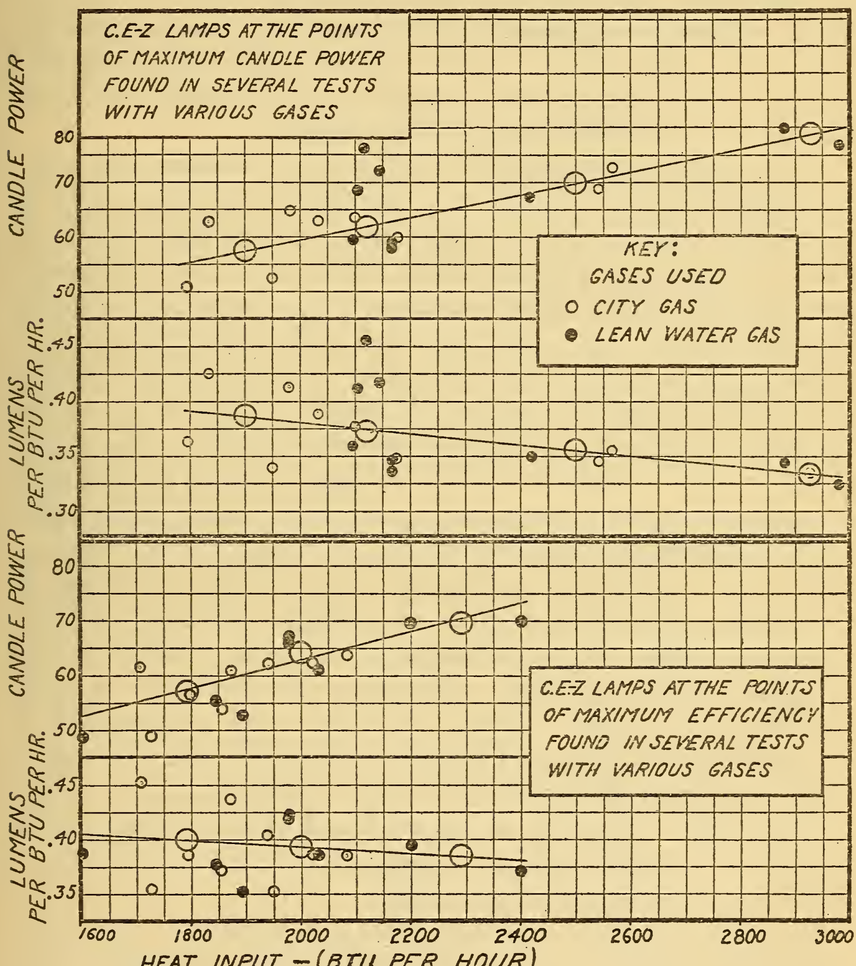

FIG. 11.—*Performance of C. E-Z lamps with various gases at various rates of heat input*

From these curves it will be seen that the higher the heat input of a lamp happens to be at maximum candlepower or at maximum efficiency, the higher is the candlepower produced. This is to be expected unless there was a marked decrease in efficiency at the higher rates.

If adjusted from time to time to maintain maximum efficiency under changing atmospheric or other conditions, the smaller lamps seem to show markedly lower efficiencies the higher the heat input per hour for such adjustment happens to be. With similar variations the upright lamps do not change in efficiency, while the inverted lamps show higher efficiencies with higher rates of heat input. When the adjustment to maximum candlepower is maintained, the small lamps and the upright lamps show behaviors similar to those just described, but the inverted lamps show lower efficiencies with higher rates of heat input.

If very exact determination of the relation between heat input and efficiency were possible, it is presumed that there would be found some optimum rate of heat input for each lamp with each gas. The degree of reproducibility attainable in the adjustment and condition of gas lamps is, however, not sufficient to permit determination of this optimum point and hence the curves of efficiency given in Figs. 8–11 are drawn as straight lines as nearly as possible through the centers of gravity (shown as ⊙ on the curves) of the various groups of individual entries. The degree of uncertainty in position or slope of these curves is evident from a consideration of the scattering of individual points on the plots.

The variation in candlepower and efficiency of the lamps at the points of maximum candlepower and maximum efficiency is the result of the large number of variables which affect these results, including lamp conditions, atmospheric conditions, and variations in the gas itself. But even considering all of these variables it is rather surprising that for these adjustments of maximum candlepower and maximum efficiency there should be found such great differences in the rate of heat input as is shown by these curves; however, it was not found that the heating value or kind of gas used had any consistent effect upon the rate of heat input at these maximum points.

This variation shows how difficult it is to secure any significant photometric results on gas-mantle lamps without extremely long series of comparisons; and it makes clear why the calculations of various experimenters often disagree because of the limited number of tests used by each as a basis of his conclusion.

If an experimenter is to secure reproducible results, he must have perfect control of the atmospheric conditions, including barometric pressure, humidity, and freedom from dust, absolutely clean passages in the lamp for gas and air, uniformity of mantle composition and quality, freedom from drafts, and a very unusual

mechanical perfection in the form of lamp, since even a very slight irregularity or lack of symmetry of the entering gas stream will often have a very marked effect on the amount of air entrained and on the position of the flame in the mantle, thus affecting both the total output and the distribution of the light. This high mechanical perfection may be of little consequence in the ordinary use of the lamp; but for accuracy of laboratory tests it is an essential feature.

6. FLUCTUATION OF GAS QUALITY

A series of tests was undertaken to ascertain the effect upon the efficiency of a lamp of changing the quality of the gas supplied to it without altering the adjustments of the gas and air supply. The set-up for these tests was so arranged that either of two different gases or a mixture of them in any desired proportions could be supplied to the lamp. Each gas was metered separately and when a mixture was used the mixture was also metered by a third meter. When a mixture of gases was used, the heating value of the mixture was computed from the proportion of gases of known heating value present.

In performing a test, the lamp being tested was adjusted to produce its maximum candlepower when operated at a fixed pressure with a given gas of known heating value. The meter passing the mixed gas was allowed to operate a sufficient length of time on the determined mixture, to purge out any other gas remaining in it. A set of photometric observations was made and the rate of gas consumption noted. From these data the efficiency of the lamp under the existing conditions could be computed. The gas quality supplied to the lamp was then changed, the adjustment of the lamp remaining unchanged. Observations were made as before and the efficiency again computed. The lamp having been operated on various gases at one adjustment, the adjustment was then changed to produce maximum candlepower with a different gas or mixture of gases. The efficiency of operation was then determined with different gases under the new condition.

The results obtained in typical series for four kinds of lamps are shown by the curves of Fig. 12. In the work there shown the gases used were water gas from 540 to 575 Btu, city gas from 625 to 660 Btu, and gas specially enriched with benzene vapor to about 750 Btu.

As will be noted from these curves, there is in most cases a distinct increase in operating efficiency when a lamp adjusted to maximum candlepower with one gas is operated on a leaner gas without change of adjustment, and a more marked decrease

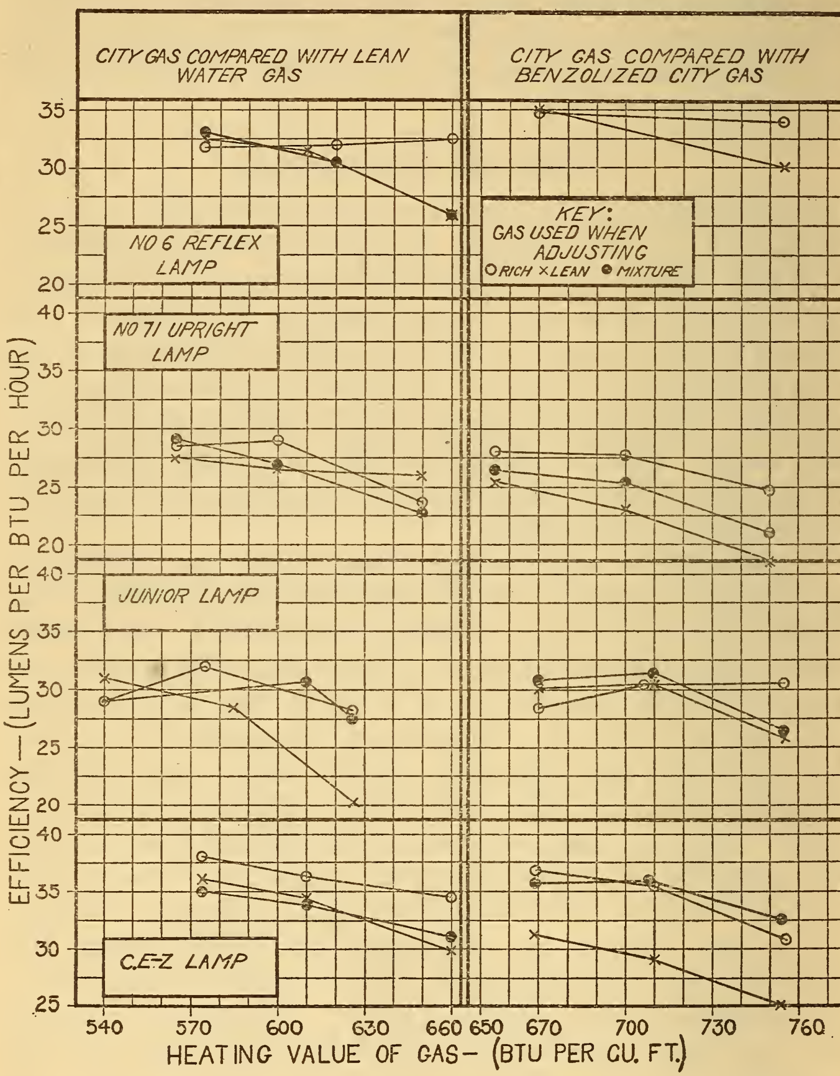

FIG. 12.—*Influence of gas quality on lamp efficiency with fixed adjustment*

in efficiency when a lamp adjusted with lean gas is operated with richer gas, all other conditions remaining unchanged. The explanation of this seems to be that when a lamp is adjusted to produce maximum candlepower with a given gas it is using more

gas than when adjusted to maximum efficiency, except in unusual cases when the maximum-candlepower and maximum-efficiency points are coincident. Consequently, a lamp adjusted to produce maximum candlepower with a rich gas is brought nearer to its maximum-efficiency adjustment when a lower quality gas is substituted, the diminution in the heat supplied in the latter case tending to bring the lamp nearer to this maximum-efficiency point. On the other hand, if a lamp adjusted to give maximum candlepower on a lean gas is operated without readjustment on a rich gas, the result is that it is supplied with such an excess of heat over the amount which it can efficiently utilize that its operation is still further removed from the maximum-efficiency point and the efficiency suffers a very marked decrease.

It will be noted also that in some cases a lamp adjusted to a rich gas shows an increased efficiency when operated on a gas of medium quality and the efficiency then decreases when a still leaner gas is used.

The curves show occasional exceptions to the general behavior in cases where a decrease in efficiency is found when using lean gas in lamps adjusted for rich gas. The explanation seems to be that the lamp was not actually adjusted to the maximum candlepower in the first place. Considerable difficulty was experienced with some lamps in getting the true maximum candlepower because of small mechanical defects in the adjusting device, which caused a shifting of the position of the gas flame within the mantle, thereby causing an abnormal variation in the candlepower in the direction of the photometer. Had it been practicable to have determined the mean-spherical candlepower directly in all cases, many of these variations might have been eliminated. The Junior burner, in particular, gave erratic results because the needle valve of the gas adjustment was not accurately centered. It was found that an accurately machined valve improved the performance of the lamp very markedly.

The following conclusions applicable in nearly all cases covered by these experiments have been drawn from them:

1. A given fluctuation in gas quality produces less change in the efficiency of operation of a lamp with lean gas than with rich gas.

2. If a lamp is adjusted for maximum candlepower, an increase in the heating value of the gas supplied to it produces a decrease in efficiency; and a decrease in the heating value produces an increase in efficiency.

7. PECULIARITIES OF INDIVIDUAL UNITS

While studying the effect of different variables on a given lamp, tests were made on different lamps using the same gas with each, and keeping all other conditions constant, to determine the comparative operation of various lamps of the same type. It was found that in many cases the difference between the individual lamps was quite as great as the effect of a changing variable. However, it was found that, in general, all lamps of a type were affected the same way by a variable and that the

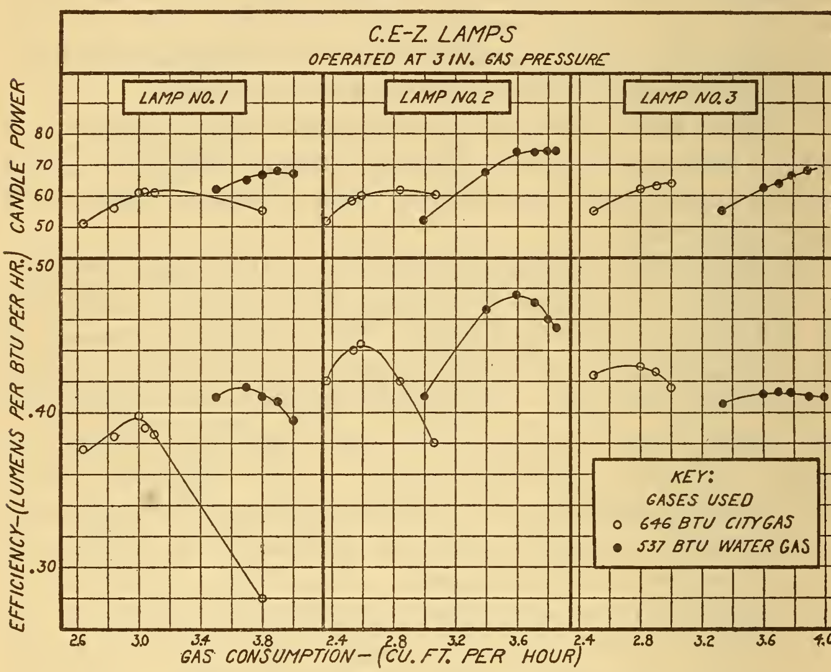

FIG. 13.—*Comparison of three similar lamps operated with the same gases*

relative effects were comparable even though the absolute values were different. The comparative operation of three C. E-Z lamps under the same conditions is shown in the curves of Fig. 13.

From these curves it will be noted that whereas two of the lamps show an increase in efficiency with the lower-quality gas, the third lamp shows slightly higher efficiency with the richer gas. It will be observed from the curves that each lamp reached a maximum efficiency and there was apparently no obstruction in any one of them preventing an adequate supply of gas. It seems quite probable that the variations are, in fact, due to some

slight differences in the sizes and shapes of the mantles on the various lamps. It has been found that there are similar differences between individual lamps of other types.

When lamps of different makers are compared there seem to be more marked differences. For example, it was found that some very cheap upright lamps gave higher efficiencies than more expensive ones, although the latter seemed to be capable of giving higher candlepowers. The causes of this behavior were not evident, though it seems likely that one cause was the different method of gas adjustment. It should be remarked that the flimsy construction of the cheap lamps might result in greatly decreased efficiency after operation for a short time.

V. GENERAL CONCLUSIONS

With uniform gas quality and with good conditions of service in other particulars the usefulness for mantle lighting of lean water gas of the qualities studied compared with rich water gas is slightly higher, for some types of lamps, than in proportion to the total heating values. Comparing lean coal gas and lean water gas of the qualities tested, the coal gas is slightly less useful, and this difference is about the same as the difference between the two qualities of water gas. Hence, it may be concluded that the usefulness of a uniform quality of coal gas of 550 to 575 Btu per cubic foot as compared with a uniform supply of richer water gas (e. g., one meeting a 22-candlepower requirement) is substantially in proportion to the heating values of the two gases. However, greater fluctuations in Btu per cubic foot, slightly greater difficulties in adjustment, and the other factors met in commercial use of lamps make the higher quality gas somewhat less desirable per heat unit for general use than either of the two kinds of lean gas.

The influence of gas quality and other factors when the gas is burned in cooking, oven-heating, and water-heating appliances will be discussed in another publication of this Bureau.

Further investigations are planned by the Bureau to extend the scope of this work and to include more unusual supplies such as blue water gas, producer gas, etc., and to obtain further general information on the subjects thus far only partly investigated.

WASHINGTON, August 5, 1917.

APPENDIX

DATA CONCERNING VARIOUS GASES USED

1. CITY GAS

Gas No.	Btu per cubic foot	Open-flame candle-power	Specific gravity	Dew point		Analysis						
				Water	Oil	CO_2	O_2	Ill.	CO	CH_4	H_2	N_2
1	648	16.8				5.4	0.2	8.9	18.4	25.8	32.5	8.8
3	664	18.6	0.63	69	48	4.5	.0	11.4	20.2	25.1	34.9	3.9
4	661	19.6	.65	65	48	2.8	.7	11.6	20.6	25.4	34.8	4.1
5	664	23.4	.66	50	47	4.4	1.3	10.9	19.4	23.7	34.3	6.0
6	662	17.2		68	50	3.7	.4	11.4	19.3	25.7	34.8	4.7
8	670	18.0	.60	68	52	2.3	.2	12.2	20.5	16.3	42.4	6.1
10	670	17.7	.60	68	52	4.0	.6	11.9	20.1	24.9	33.9	4.6
12	663	17.8	.59	66	52	4.1	.0	9.7	19.0	27.2	36.7	3.3
14	670											
16	662	18.8	.60	73	50	3.9	1.3	10.8	19.8	24.9	35.5	3.8
18	651	17.2	.60	72	48	4.2	.9	10.8	21.8	23.4	35.2	3.7
20	644	16.0	.60	71	49	4.0	1.1	10.1	20.3	24.1	36.4	4.0
22	638	15.3	.62	66	49	4.4	.8	10.0	21.9	23.2	34.5	5.2
24	640	16.3	.61	67	46	4.5	.3	10.1	21.6	24.2	34.5	4.7
26	652	16.8	.61	68	47							
28	649	15.8	.60	68	52	4.2	.5	9.7	21.0	22.5	38.1	4.0
30	665			72	53							
37	634											
43	660	18.6										
46	665											
47	626											
49	636											
52	666	18.5										
54	669	17.5										
56	670	19.0										
58	660											
60	648					4.4	.4	10.0	17.5	25.8	33.4	8.5
63	648											
64	618											
67	639											
68	640											
70	640											
71	636											
72	631											
74	631											
75	624											
75a	636											
77a	680											
88	665											
89	656											
90	654											
91	663											
94	669											
96	640											
98	646											
99	645											
101	658											
103	629											
104	686											
106	651											
108	650											
122	632	14.9										
123	633											

DATA CONCERNING VARIOUS GASES USED—Continued

2. BENZOLIZED CITY GAS

Gas No.	Btu per cubic foot	Open-flame candle-power	Specific gravity	Dew point		Analysis						
				Water	Oil	CO_2	O_2	Ill.	CO	CH_4	H_2	N_2
2	697	25.8	....	....	....	1.2	1.3	13.7	16.6	23.1	39.8	4.3
7	781	25.0	....	69	56	4.2	.5	16.4	19.3	24.6	33.6	1.4
9	728	24.0	0.64	67	53	4.3	.3	12.7	19.7	31.2	26.3	5.5
11	724	24.0	.65	61	52	4.0	.0	11.4	21.0	....	....	....
13	737	25.0	.63	65	54	4.1	.3	11.4	19.9	25.3	34.2	4.8
44	695	29.1	....	....	....	....	....	....	....	....	....	....
45	664	24.9	....	....	....	4.4	1.1	10.8	14.5	21.1	42.8	5.3
51a	771	25.9	....	....	....	....	....	....	....	....	....	....
53	753	25.8	....	....	....	....	....	....	....	....	....	....
55	755	26.2	....	....	....	....	....	....	....	....	....	....
121	651	20.7	....	....	....	....	....	....	....	....	....	....

3. WATER GAS

Gas No.	Btu per cubic foot	Open-flame candle-power	Specific gravity	Water	Oil	CO_2	O_2	Ill.	CO	CH_4	H_2	N_2
15	548	10.0	0.57	65	36	4.5	0.5	8.0	24.5	18.1	40.2	4.2
17	539	7.0	.58	72	47	5.3	1.0	7.6	24.0	18.7	39.1	4.2
19	537	6.9	.59	73	49	4.9	.2	7.0	24.9	18.7	41.6	2.7
21	530	5.6	.60	68	46	4.9	.4	6.6	28.6	16.6	38.8	4.1
23	542	6.4	.63	67	48	5.9	.8	7.3	28.9	18.6	34.2	4.3
25	541	6.1	.62	65	47	5.5	.5	6.8	28.6	17.4	36.6	4.5
27	525	4.8	....	62	46	5.7	.9	6.9	28.7	16.7	37.6	3.5
29	551	6.8	.61	....	....	5.0	.4	7.5	26.9	13.6	46.4	4.0
41	523	....	....	....	....	4.5	1.0	9.2	21.3	17.4	41.4	5.2
42	487	....	....	....	....	6.1	.9	6.2	24.1	....	....	....
57	575	13.4	....	....	....	3.2	.1	4.6	27.3	18.5	40.6	5.6
59	565	....	....	....	....	5.1	.1	7.1	24.5	19.7	37.6	5.9
61	561	....	....	....	....	3.0	1.1	6.8	23.6	19.3	41.3	4.9
65	580	....	....	....	....	....	....	....	....	....	....	....
66	553	....	....	....	....	3.0	1.4	6.8	28.6	18.1	36.0	6.1
69	550	....	....	....	....	3.2	2.6	6.4	25.7	17.7	29.9	14.5
73	550	....	....	....	....	4.1	1.5	7.5	19.9	21.1	40.1	5.8
76	554	....	....	....	....	....	....	....	....	....	....	....
77	548	....	....	....	....	....	....	....	....	....	....	....
79	567	....	....	....	....	....	....	....	....	....	....	....
80	590	....	....	....	....	....	....	....	....	....	....	....
81	544	....	....	....	....	3.5	.8	7.4	28.3	20.5	33.7	5.8
83	567	....	....	....	....	3.3	.8	8.1	30.2	33.8	19.1	4.6
86	570	....	....	....	....	4.1	4.2	5.9	24.3	17.1	44.0	.4
87	566	....	....	....	....	3.4	.6	7.4	31.8	20.8	32.7	3.3
92	580	....	....	....	....	....	....	....	....	....	....	....
93	574	....	....	....	....	....	....	....	....	....	....	....
95	561	....	....	....	....	3.2	2.1	7.0	32.2	16.8	29.7	9.0
97	537	....	....	....	....	....	....	....	....	....	....	....
100	567	....	....	....	....	....	....	....	....	....	....	....
102	573	....	....	....	....	....	....	....	....	....	....	....
105	570	....	....	....	....	....	....	....	....	....	....	....
107	554	....	....	....	....	....	....	....	....	....	....	....
109	561	....	....	....	....	....	....	....	....	....	....	....
110	558	....	....	....	....	....	....	....	....	....	....	....
116	582	....	....	....	....	1.8	.6	7.5	25.9	18.0	37.7	8.5
118	575	....	....	....	....	2.4	1.0	7.1	27.3	19.0	35.6	7.6

4. COAL GAS

Gas No.	Btu per cubic foot	Open-flame candle-power	Specific gravity	Water	Oil	CO_2	O_2	Ill.	CO	CH_4	H_2	N_2
38	575	....	....	....	....	4.0	0.9	4.1	5.1	28.6	53.9	3.4
39	592	....	....	....	....	3.8	1.1	3.2	5.6	31.8	52.2	2.3
40	572	....	....	....	....	4.9	.3	3.0	4.6	31.8	52.6	2.8
62	561	....	....	....	....	6.3	.4	6.1	8.2	25.5	47.0	6.5
78	540	....	....	....	....	3.2	3.1	3.1	7.3	28.9	39.0	15.4
82	570	....	....	....	....	4.2	.7	3.6	9.3	33.0	46.7	2.5
84	540	....	....	....	....	9.0	3.4	4.7	7.1	27.7	41.4	6.7
85	564	....	....	....	....	5.5	.8	3.1	8.5	32.3	44.4	5.4
111	573	....	....	....	....	....	....	....	....	....	....	....
117	576	....	....	....	....	2.7	.0	3.7	7.0	22.1	57.8	6.7
119	575	....	....	....	....	3.4	.5	4.5	11.3	19.1	53.2	8.0
120	580	....	....	....	....	2.2	1.0	3.0	7.5	30.0	48.7	7.6